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TERTIARY VERTEBRATE PALEONTOLOGY,

STRATIGRAPHY, AND STRUCTURE,

NORTH BOULDER RIVER BASIN, JEFFERSON COUNTY, MONTANA

by

Donald L. Lofgren

B.A., University of Minnesota, 1983

presented in partial fulfillment of the requirements

for the degree of

Master of Science

UNIVERSITY OF MONTANA

1985

Approved by:

Robert W. Fields

Chairman, Board of Examiners

Dean, Graduate School

June 26, 1985

Date

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ABSTRACT

Lofgren, Donald L., M.S., June 1985 Geology

Tertiary vertebrate paleontology, stratigraphy, and structure, North Boulder River basin, Jefferson County, Montana (113 p.)

Director: Dr. Robert W. Fields RWF

The North Boulder River basin is a north-northwestward trending fault-bounded Tertiary basin that contains a nonmarine basin-fill sequence of continental clastic rocks. The Renova (early Oligocene-early Miocene) and Six Mile Creek (middle Miocene) formations constitute basin-fill sediments with total aggregate thickness approaching 800 m. Vertebrate fossils collected throughout the basin are the basis for age determinations and indicate Chadronian-Late Arikareean (Renova Fm.) and Early Barstovian (Sixmile Creek Fm.) Land Mammal Ages for these sedimentary deposits.

Chadronian (early Oligocene) sediments record primary localized mass-flow (Dunbar Creek Member) and fluvial-floodplain (Climbing Arrow Member) deposition. Distribution patterns of these sediments indicate the existence of a southeastward draining alluvial plain that probably extended into the Three Forks basin. Late Arikareean (early Miocene) sediments (Negro Hollow Beds) represent primary mass-flow with minor fluvial-floodplain and lacustrine (?) deposition. A middle Tertiary erosional unconformity is indicated by a biostratigraphic gap encompassing all of the Hemingfordian Land Mammal Age (middle Miocene). An unknown amount of Renova Formation sediment was removed by this erosional event. Locally derived, coarse-grained Early Barstovian (middle Miocene) sediments indicate an alluvial fan depositional environment. Uplifts in the Negro Hollow-Doherty Mountain and Bull Mountain areas contributed to the growth of these fans. The previously developed southeastward draining alluvial plain was truncated by these uplifts and the present day basin was delineated.

The North Boulder River basin is bounded on the east by the Starretts Ditch fault. Western basin-bounding faults are minor. Early basin development is obscure and initial basin existence is indicated by the preservation of early Oligocene (Renova Fm.) sediments. Evidence for faulting during Renova Formation deposition (early Oligocene-early Miocene) is not documentable. Middle Miocene uplifts were locally centered and probably continued into the late Miocene. Late Miocene-early Pliocene extensional stresses resulted in major fault block displacement. Listric normal faults accommodated block subsidence and the Tertiary section rotated into the Starretts Ditch fault.

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CHAPTER 1

INTRODUCTION

Mountain ranges in southwestern Montana are separated by broad intermontane basins (Kuenzi and Fields, 1971). These basins began to form at the end of the Laramide orogeny. Post-compression steep faulting along with extensive erosion outlined the basins, and by the late Eocene a pre-basin fill erosion surface probably was completed (Kuenzi and Fields, 1971). These basins are filled with Tertiary continental sediments that can exceed 5,000 m in thickness but typically are less than 1,500 m thick (Thompson and others, 1982).

Kuenzi and Fields (1971) have developed a general stratigraphic framework for several Montana basins which consists of two lithologically distinct sedimentary packages that are included in the Bozeman Group (Robinson, 1963). The late Eocene-early Miocene Renova Formation comprises the lower sequence and consists of mainly fine-grained sediment derived principally from volcanic ash. The overlying middle Miocene-late Miocene Six Mile Creek Formation is a coarser-grained sequence composed chiefly of sand and gravels (Thompson and others, 1982). The contact between these sedimentary units is interpreted by most workers as an erosional

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and angular unconformity which is regional in extent (Robinson, 1963; Kuenzi and Richard, 1969; Kuenzi and Fields, 1971; Hoffman, 1971; Petkewich, 1972; Rasmussen, 1973; Monroe, 1976), although a recent study of the Jefferson basin questions the validity of this unconformity (Axelrod, 1984).

North Boulder River Basin

The North Boulder River basin is a north-northwest-trending fault-bounded Tertiary basin that subparallels earlier Laramide structural trends (Figure 1) (Woodward, 1981; Schmidt and O'Neill, 1982). The basin is located in Jefferson County and is bounded by the Elkhorn Mountains to the north, Bull Mountain to the west, Red Hill to the south, and Doherty Mountain and associated features to the east. Only the southern half of the basin, between Red Hill and approximately one mile north of McKanna Spring, was surveyed because of the almost total absence of Tertiary outcrops in the northern half (Plate I). This area covers portions of the 15-minute Devil's Fence and Jefferson Island U.S. Geological Survey quadrangle sheets.

The Tertiary basin-fill sequence includes sediments lithologically and temporally referable to the Renova and Six Mile Creek formations which together may total

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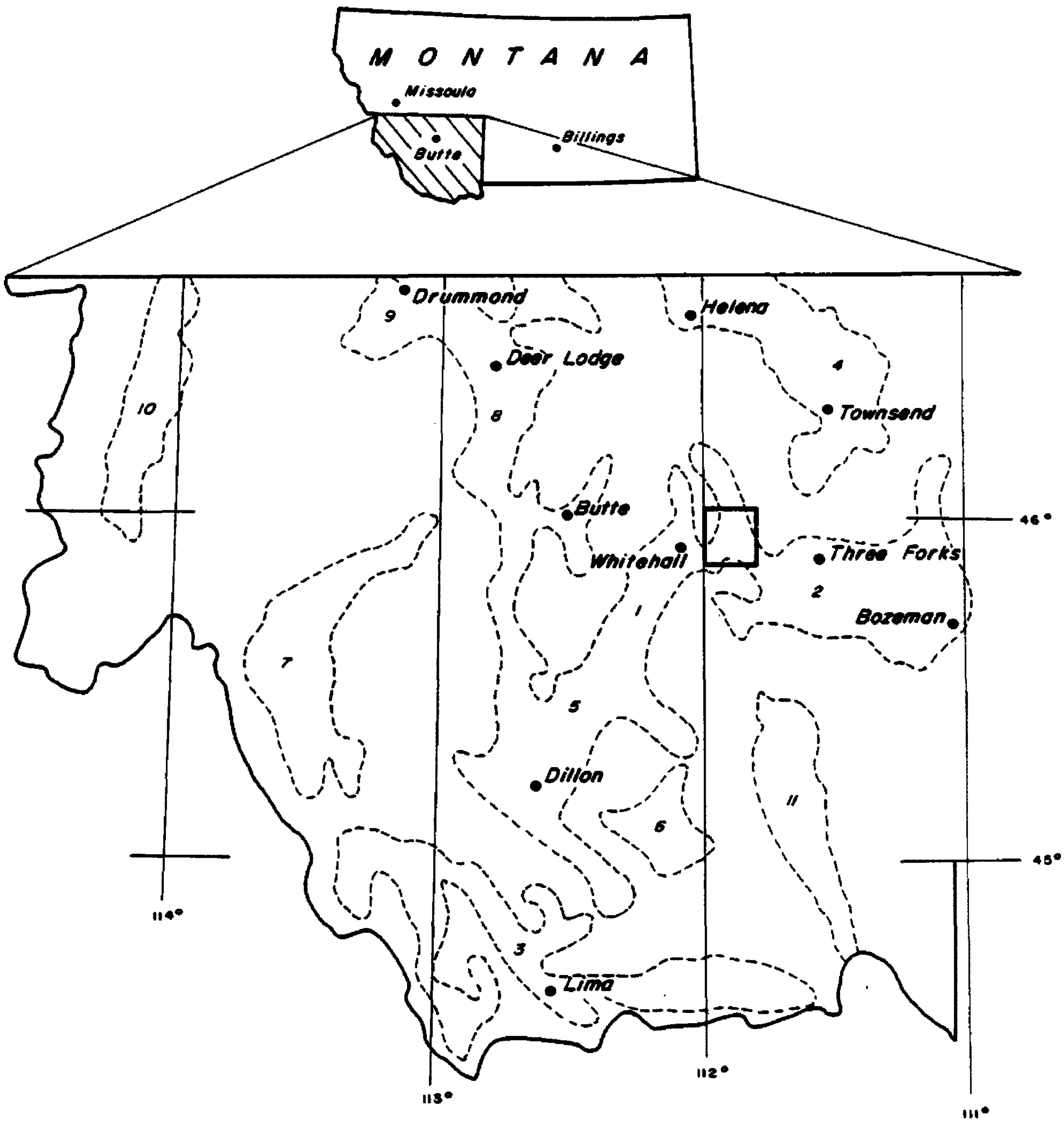

Figure 1. Tertiary intermontane basins of southwest Montana (ruled). Study area is enclosed within the block outlined near Whitehall, Mt. Key to basins: 1) Jefferson; 2) Three Forks; 3) Lima; 4) Townsend; 5) Beaverhead; 6) upper Ruby; 7) Big Hole; 8) Deer Lodge; 9) Flint Creek; 10) Bitterroot; 11) Madison (modified from Kuenzi and Fields, 1971).

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1,460 m of section just north of McKanna Spring (Burfeind, 1967). These two sedimentary packages are separated locally by an erosional unconformity that spans approximately 5 m.y. and is exposed just north of Negro Hollow (T3N, R2W, sec. 28). In the western portion of the basin (T3N, R3W, sec. 23-26, 35-36) the unconformity is not exposed. This unconformity is interpreted to be regional in extent and may be expressed angularly as well as erosionally in other Tertiary basins of southwest Montana (Fields and others, 1985).

Purpose and Previous Work

This study was undertaken to provide detailed information on the Tertiary geology of the North Boulder River basin. The study was subdivided into three broad areas of investigation:

1. Sedimentology and stratigraphy. Previous workers in the North Boulder River basin dealing with this discipline included descriptions and brief interpretations concerning the Tertiary sediments as part of larger regional studies (Alexander, 1955; Klepper and others, 1957; Richard, 1966). Their treatment of the Tertiary , however, was incomplete and of a superficial nature. One purpose of this study was to focus investigation on Tertiary sediments and formulate

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a stratigraphic framework from which a sedimentological-depositional history could be elucidated.

2. Vertebrate Paleontology. Previous collections of vertebrate fossils from the North Boulder River basin are housed in the Carnegie Museum, American Museum of National History, and the University of Montana Museum of Paleontology. Many new species of vertebrates were described from specimens in these collections (Douglass, 1903; Clark, 1941; Schultz and Falkenbach, 1940, 1950, 1954). Based on those reports a partial list of taxa was published and consisted of two general local faunas (Fields and others, 1958). Assignment of precise stratigraphic and geographic localities to many of these taxa is impossible because of the unfortunately imprecise record-keeping by early paleontologists, which renders most of this information biostratigraphically useless. The present study combines usable previous work with further collecting to develop a series of local faunas from which a well-documented biostratigraphic framework can be demonstrated.

3. Structure. Pardee (1950), Alexander (1955), Aram (1979), and Streeter (1983) have reported the locations of Tertiary faults within or proximal to the North Boulder River basin. Discussion of faults by these authors generally includes only one localized

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area of the basin. The present study included detailed mapping of faults in order to interpret the sequence of faulting and history of basin development.

Methods

Detailed geologic mapping of Tertiary rock types (1:24,000 scale) was completed in 50 field days during the summer of 1984. Mapping emphasized the recognition of lithologic textures, compositions, contacts, and sedimentary structures. From this, depositional processes active during basin filling were interpreted and a depositional environmental framework was formulated. Numerous vertebrate fossils were collected and used to establish biostratigraphic age control for the lithologic units mapped. The depositional environmental framework was combined with the biostratigraphic data to elucidate a depositional history for the basin. Bedding attitudes and disruptions in the distribution of Tertiary strata were used to identify tectonic movements and features along with fault geometry. These data were analyzed to formulate a geologic history for the basin.

North American Land Mammal Ages (NALMA) used to define the biostratigraphic framework of the North Boulder River basin follows the recent update by Tedford

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and others (in press). Absolute ages which define this framework follow the recently published geologic time scale of Lillegraven and others (1981).

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CHAPTER 2

VERTEBRATE PALEONTOLOGY

INTRODUCTION

Vertebrate fossil localities are numerous in the North Boulder River basin. Twenty-six new sites were discovered, and two previously known Montana vertebrate localities were resampled. Two hundred forty specimens representing seventeen genera were collected and identified. No new species are proposed, although incompletely prepared material tentatively referred to as *Dinohyus hollandi* may prove to be a new species.

Carnegie Museum of Pittsburgh and American Museum of Natural History specimens are incorporated into this study where assignment of a Montana vertebrate locality to the material could be accomplished by using collectors' field descriptions and photos. If a specimen could not be assigned a Montana vertebrate locality with reasonable certainty, it was omitted from this study.

The vertebrate fossils collected in the North Boulder River basin are divided into three local faunas: the Monforton Ranch local fauna, the Negro Hollow local fauna, and the McKanna Spring local fauna. Each local fauna is discussed separately with respect to its taxonomic composition and correlative age assignment. The systematic

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paleontology is presented in Appendix I and is organized by local faunas. Oreodont material is referred to by the taxonomic names used by Schultz and Falkenbach (1940, 1950, 1954, 1968), although Lander's (1977) revised classification is also noted.

FAUNAL LISTS

Monforton Ranch Local Fauna

MV8405 : *Macrotarius montanus*
Aepinacodon sp.

MV8407 : *Teleodus* cf. *primitivus*
camelid

MV8409 : cf. *Oreonetes anceps*

MV8427 : cf. *Oreonetes*
brontothere
rhinocerotid

MV8430 : brontothere
Merycoidon culbertsoni
(*Prodesmatochoerus natronensis*; Lander, 1977)
Merycoidon gracilis
(*Oreonetes*, new species; Lander, 1977)

Negro Hollow Local Fauna

MV5907 : *Diceratherium* cf. *armatum*
Merycoides longiceps

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Pseudodesmatochoerus longiceps
(_Merycoides longiceps_; Lander, 1977)
Hypsiops brachymelis
(_Hypsiops breviceps_; Lander, 1977)
Pseudomesoreodon rolli
(_Hypsiops bannackensis_; Lander, 1977)
Pseudomesoreodon boulderensis
(_H. bannackensis_; Lander, 1977)
Oxydactylus lacota
Stenomylus cf. _hitchcocki_
camelid
Nanotragulus sp.

MV8423 : rhinocerotid
equid
Hypsiops breviceps
Merycoides longiceps
merycoidodontid
cf. _Oxydactylus lacota_
camelid

MV8424 : rhinocerotid

MV8425 : lagomorph
Allomys sp.
rodent
Peratherium sp.
cf. _Nothocyon geismarianus_

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cf. *Nothocyon*

equid

merycoidodontid

MV8426 : *Dinohyus hollandi*

McKanna Spring Local Fauna

MV6003 : *Mylagaulus* sp.

Leptarctus cf. *bozemanensis*

Merychippus seversus

Merychippus cf. *seversus*

Merychippus cf. *isonesus*

Merychippus cf. *intermontanus*

cf. *Merychippus* sp.

Aepycamelus proceras

Aepycamelus sp.

camelid

cf. *Merycodus*

Paracosoryx sp.

Merriamoceras sp.

MV8411 : cf. *Merychippus* sp.

MV8412 : cf. *Merychippus* sp.

MV8414 : *Merychippus* cf. *seversus*

Merychippus cf. *isonesus*

cf. *Merychippus* sp.

Aepycamelus proceras

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Aepycamelus sp.
camelid

MV8415 : *Merychippus seversus*

MV8416 : *Brachycrus laticeps*

MV8417 : *Merychippus* cf. *seversus*
cf. *Merychippus* sp.
camelid

MV8418 : *Aelurodon* cf. *saevus*
Merychippus seversus
cf. *Merychippus* sp.
camelid

MV8419 : *Merychippus seversus*
cf. *Merychippus* sp.

MV8420 : cf. *Merychippus* sp.

MV8422 : *Merychippus* cf. *seversus*
cf. *Merychippus* sp.

Monforton Ranch Local Fauna

Material for this local fauna came from five widely separated localities situated in the southern half of the North Boulder River basin. Vertebrate fossils are rare in these localities, but the few taxa that were identified were sufficient to allow an age interpretation.

This local fauna is representative of the Chadronian (Late Eocene and Early Oligocene) N.A.L.M.A. (see Table I).

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Table I. N.A.L.M.A. of Monforton Ranch Taxa

Taxa	Age	Source
Oreonetes	middle Chadronian	Schultz and Falkenbach, 1968
Oreonetes (new sp.)	late middle Chadronian	Lander, 1977
Prodesmatochoerus natronensis	late middle Chadronian	Lander, 1977
Aepinacodon	Late Chadronian to Early Orellan	Macdonald, 1956
Macrotarius montanus	Chadronian	Clark, 1941
Teleodus primitivus	Chadronian	Scott, 1941
brontothere	Last appearance Chadronian	Wood and others, 1941

DISCUSSION: The published age data for these taxa clearly indicate a Chadronian age for this local fauna. More precisely, the oreodonts indicate a middle Chadronian age. MV8407 is probably slightly older than this because *Teleodus primitivus* is known only from the base of the Cypress Hills Formation of Saskatchewan, considered by Savage and Russell (1983) to be Early Chadronian.

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Negro Hollow Local Fauna

Five fossil localities comprise the Negro Hollow local fauna. This fauna was previously known as the North Boulder Valley, Boulder Valley North, or Cold Spring P. O. fauna (Savage and Russell, 1983; Tedford and others, in press). It is renamed to avoid future confusion with other local faunas within the same river drainage.

The fossil material of this local fauna is for the most part typical of the Arikareean (Late Oligocene-Early Miocene) Land Mammal Age. Wood and others (1941) listed *Oxydactylus*, *Diceratherium*, *Dinohyus*, and *Stenomylus* as index fossils for the Arikareean. Tedford and others (in press), in an update, list *Allomys* and *Nanotragulus* as first appearance fossils. Last appearance fossils are entelodonts and *Nothocyon* (Wood and others, 1941).

More precisely, the fossil vertebrates suggest a Late Arikareean (Early Miocene) age. *Dinohyus hollandi* and *Stenomylus hitchcocki* are best known from the Harrison beds at Agate Springs quarry near Agate, Nebraska (Wilson, 1957). These beds are considered to be Late Arikareean in age (Savage and Russell, 1983; Tedford and others, in press). *Oxydactylus lacota* is confined to Late Arikareean sediments of the Marsland and Upper Harrison formations, according to McKenna (1966).

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Oreodonts are fairly common in the Negro Hollow local fauna, but their usefulness for regional stratigraphic correlation in the North Boulder River basin is uncertain. Lander (1977), in his review of the oreodonts, states that Hypsiops breviceps is indicative of the Late Arikareean and Hypsiops bannackensis and Merycoides longiceps are known only from beds of Early Hemingfordian age. Schultz and Falkenbach (1968), in an earlier revision, propose a Late Arikareean age for the same specimens Lander (1977) has stated indicate both Late Arikareean and Early Hemingfordian ages. The specimens in question were all collected from the same locality (MV5907) in the North Boulder River basin (Schultz and Falkenbach, 1950; R. Tedford, pers. comm., 1984). This would suggest that taxa named and described from this material should be considered the same age. Lander (1977), in synonymizing many previously described taxa of oreodonts, has apparently assigned different age dates to specimens collected from one locality (MV5907) in the North Boulder River basin.

A similar situation is reported by Runkel (in prep.) from the Smith River basin, Montana. Two separate genera of oreodonts interpreted by Lander (1977) to individually indicate a Late Whitneyian and middle Arikareean age were collected by Koerner (1939) from the same locality

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(Runkel, in prep.). Also, in the North Boulder River basin *H. breviceps* was collected (MV8423, this report) stratigraphically above *M. longiceps*. This is in apparent conflict with Lander's (1977) proposed age interpretations. The oreodonts at MV5907 are stratigraphically associated with *D. hollandi*, *O. lacota*, and *S. hitchcocki* and therefore probably should be considered Late Arikareean in age as proposed by Schultz and Falkenbach (1968).

The Negro Hollow local fauna is similar to the Belmont Park Ranch fauna of the upper Ruby River basin of Montana. Taxa common to these two local faunas are *H. bannackensis*, *Oxydactylus*, and *Nanotragulus* (Monroe, 1976). The Belmont Park Ranch fauna was also generally considered to be indicative of the Late Arikareean or earliest Hemingfordian (Monroe, 1976).

McKanna Spring Local Fauna

Vertebrate fossil material is common and well-preserved in most of the eleven McKanna Spring localities. This is in part related to the number of well-exposed outcrops that occur in the northern part of the study area.

The McKanna Spring local fauna is characterized by the occurrence of *Merychippus*, the most abundant fossil found in all localities except MV8416. *Merychippus*, along with *Aepycamelus*, *Merycodus*, and *Mylagaulus* are

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listed by Wood and others (1941) as characteristic of the Barstovian Land Mammal Age. The single specimen of Mylagaulus is a P^4 which contains five enamel lakes. According to Shotwell (1958) this condition is indicative of a mylagaulid of Barstovian age.

More precisely, the McKanna Spring local fauna is representative of the Early Barstovian. Merychippus severus is the most common fossil in this local fauna and is a very common element in the Mascall fauna of Oregon. The Mascall fauna is Early Barstovian in age (Tedford and others, in press). Brachycrus and Merriamoceras are listed by Tedford and others (in press) as last appearance fossils for the Early Barstovian. Aepycamelus proceras is found at two McKanna Spring localities. This species is best known from the lower Snake Creek beds of Nebraska, which are considered to be Early Barstovian in age (Tedford and others, in press).

The only significant evidence of a Late Barstovian age for the McKanna Spring local fauna is the occurrence of Aelurodon cf. saevus at MV8418. Aelurodon is most often reported in Late Barstovian and Clarendonian faunas and is listed by Tedford and others (in press) as a first appearance fossil for the Late Barstovian. In the North Boulder River basin it is associated with Merychippus severus which is indicative of the Early Barstovian.

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This apparent discrepancy was also reported in the Early Barstovian Sweetwater Creek fauna of the upper Ruby River basin of Montana (Monroe, 1976). This may suggest that *Aelurodon* occurs earlier in Montana than in other regions of North America and possibly should be considered a normal part of the Early Barstovian fauna of Montana.

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CHAPTER 3

STRATIGRAPHY

INTRODUCTION

Pre-basin metamorphic, sedimentary, and igneous rocks, ranging in age from Precambrian to Cretaceous, crop out either adjacent to or in the vicinity of the North Boulder River basin. Nonmarine Tertiary sedimentary rocks unconformably overlie these older strata. The probable aggregate maximum thickness of the Tertiary continental sediments is approximately 800 m.

Tertiary stratigraphy in the North Boulder River basin is complex (Plate I). Tertiary intermontane basins of the western United States are characterized by basin fill strata that can exhibit rapid facies changes (Picard and High, 1972; Brenner and Glanzman, 1979; Axelrod, 1984). As a result, lateral and vertical relationships between lithologies representing these facies are complex (Axelrod, 1984). This situation can be further complicated by poor exposures. In the case of the North Boulder River basin, Tertiary sediments are mostly covered, with less than ten percent of the total basin surface consisting of exposed outcrops. This is especially a problem in the older Tertiary sediments in the North Boulder River basin. With this many limitations present "classical

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stratigraphy" (i.e., measuring sections, then correlating key beds between sections, etc.) is not applicable in most cases (J. Moore, pers. comm., 1984). Therefore, Tertiary sediments in the North Boulder River basin were mapped by rock type, not by formation and member.

Thirteen lithotypes were developed during mapping of the Tertiary strata of the North Boulder River basin (Plate I). Vertebrate fossils were collected from most of these lithotypes. Compilation of the age dates indicated by these fossils compared with certain lithotypes produced general trends. Certain lithotypes were commonly found in certain age periods as indicated by vertebrate fossils. These paleontological and lithological trends broadly correspond to the general stratigraphic framework developed in other Tertiary basins of southwest Montana (Robinson, 1963; Kuenzi and Fields, 1971; and others). Therefore, for purpose of clarity in discussion and because of their previous use in basin studies, this stratigraphic framework is used in the text of this report (Figure 2). Mapped lithotypes (except Tc_1) are grouped by general age and assigned to members and formations (except the Negro Hollow Beds) described by Kuenzi and Fields (1971) from the Jefferson River basin (compare Figure 3 with Plate I). It is important to note that this grouping does not suggest that field mapping of formations and

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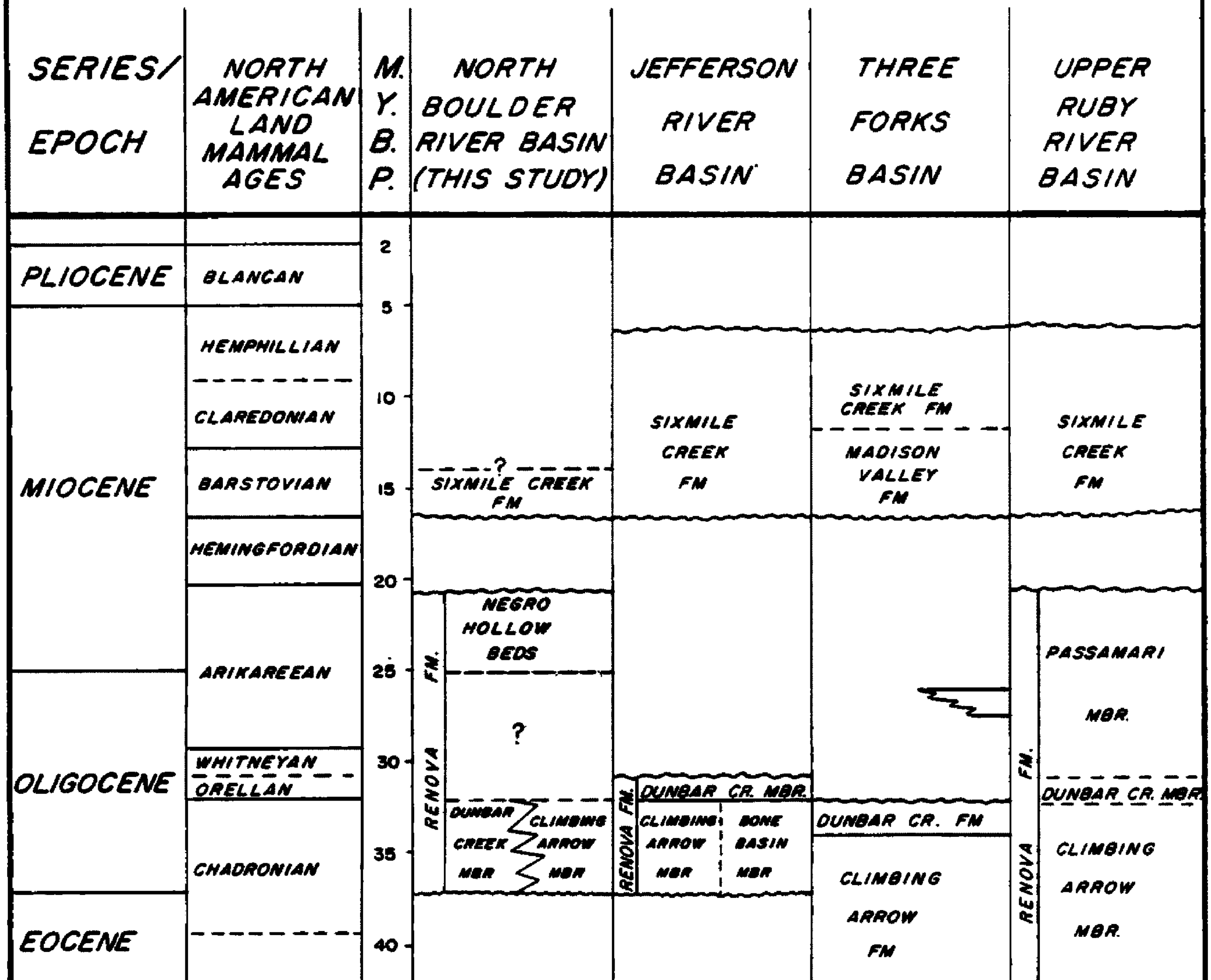

Figure 2. Stratigraphic framework and correlation chart of selected Tertiary basins. Modified from Fields and others (1985).

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members without errors is possible in the North Boulder River basin. Also, Land Mammal ages (N.A.L.M.A.) used for the biostratigraphic framework (Figure 2) should not in a strict sense indicate that isolated outcrops assigned to the same age be assumed to be time equivalent. Some margin of error is unavoidable.

The Tertiary stratigraphy in the basin is subdivided into the Renova Formation (Kuenzi and Fields, 1971) and the Six Mile Creek Formation (Robinson, 1967). Also, the Renova Formation is divisible locally into three members, the Climbing Arrow Member, the Dunbar Creek Member, and the Negro Hollow beds (local name only) on the basis of general lithological and faunal differences (Figure 2).

A fifth distinct basinal unit outcrops in only one location in the southwest section of the study area and has been termed the Conrow Creek conglomerate (Richard, 1966; Schmidt et al., 1979; Streeter, 1983) (Plate I). Although probably Tertiary in age, due to its isolated location, its temporal correlation to present stratigraphic nomenclature is unclear. In the interest of clarity, convenience, and organization, each of the Tertiary units will be discussed separately, although contacts between units when exposed will be addressed.

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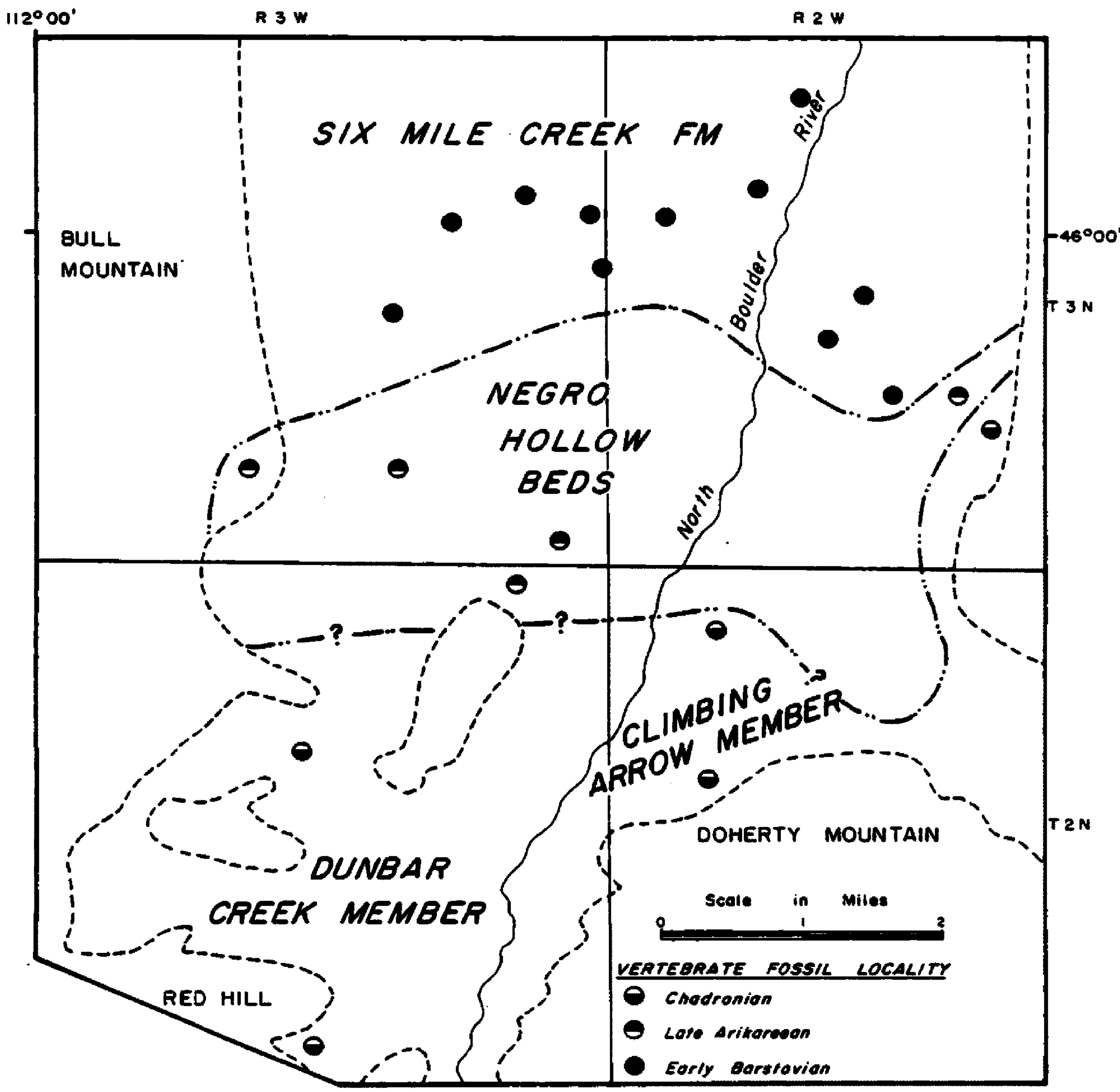

Figure 3. Approximate age distribution of exposed Tertiary sediments in the North Boulder River basin.

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CONROW CREEK CONGLOMERATE

Description

The Conrow Creek Conglomerate (Tc_1) fills an older stream valley that separates Cretaceous Elkhorn Mountain volcanics from Paleozoic sedimentary rocks (Plate I). Outcrops rise abruptly from the stream floor and form 10-meter cliffs. Clast composition is locally-derived shale and carbonate rocks with rare pebbles of volcanics present. The maximum total thickness is approximately 20 m. The conglomerate occupies an isolated basin margin location, and its relationships to other Tertiary outcrops are not discernible.

Interpretation

This matrix-supported conglomerate probably represents a remnant of a single major debris flow of unknown age that flowed down and partially filled a pre-existing stream drainage. Poorly sorted, matrix-supported, and structureless deposits of this type are indicative of debris flow deposition (Nelson, 1982; Rust and Koster, 1984). The size of the clasts and thickness of the unit suggest high-viscosity, mass-flow processes during deposition (Collinson, 1978; Nelson, 1982). Also, C_1 is similar texturally to very coarse, post-glacial lahars from

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Mt. Rainier, Washington, which are interpreted to form from mass-flow deposition (Crandell, 1971).

Clast composition and texture suggest a source area directly adjacent to the site of deposition. The presence of Cretaceous Elkhorn Mountain volcanic clasts places a Late Cretaceous age constraint on maximum time of formation. A minimum age is speculative since there is a lack of cross-cutting relationships with Tertiary basin sediments.

RENOVA FORMATION--CLIMBING ARROW MEMBER

Introduction

This part of the Renova Formation was described in the Jefferson River basin and is composed primarily of montmorillonitic mudstone-siltstone with lesser amounts of vitric siltstone, arkose, and conglomerate (Kuenzi and Fields, 1971). In the Jefferson River basin the Climbing Arrow Member is Chadronian in age (Kuenzi and Fields, 1971) (Figure 2).

In the North Boulder River basin strata assignable to the Climbing Arrow Member are homotaxially similar to the type description (Figure 2). Lithologically they are generally similar, with montmorillonitic mudstones (Tm) and siltstones (Ts_2), conglomerates (Tc_2) and sandstones (Tss) in abundance. One notable

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difference is the large amount of conglomerate (Tc_2) in this member in the North Boulder River basin (Plate I).

Description

Strata assignable to the Climbing Arrow Member of the Renova Formation are exposed north of Doherty Mountain and along the Starretts Ditch fault north of Negro Hollow (Figure 3). In general, exposures are nonresistant and mostly covered, making bedding attitudes and sedimentary structures difficult to ascertain. Outcrops are widely scattered and beds are rarely traceable for more than 10 meters. The thickness of this member is estimated to be 200 meters. Vertebrate fossils collected suggest a Chadronian age for these sediments (Figure 2).

Very thick (greater than 2 m) massive tabular beds of impure mudstone (Tm) and siltstone (Ts_2) with lesser amounts of interbedded lensoidal feldspathic quartz sandstones (Tss) and pebble conglomerates (Tc_2) characterize outcrops of this member. Colors of interbedded siltstone and mudstone exhibit a parallel striping pattern on the best exposures. These fine-grained sediments contain a high percentage of montmorillonite clay (Richard, 1966), which swell appreciably and produce popcorn-like lumps of clay and silt when wet. Calcareous nodules are common in both the clays and silts and occasionally form a thin

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irregular bounding layer between the two, otherwise contacts are gradational. Beds of unstratified siltstone composed almost entirely of devitrified glass are present but rare.

Angular-to-subrounded clast-supported sandstones and pebble conglomerates have a bimodal texture with devitrified glass composing the fine fraction. Sandstones are usually massive, but horizontal to planar stratification is faintly evident in the best exposures. Conglomerates composed primarily of granitic and volcanic fragments are well cemented with calcite and form the best outcrops of this member. Scoured bases with imbricated medium pebble lags commonly fine upward to very fine pebbles and coarse sand. Crude internal stratification consists of horizontal, low-angle, and trough cross-bedded sand and pebbles. Rarely exposed are very thick lenses of white conglomerate made up of unsorted subrounded fragments of pumice mixed with unaltered and devitrified glass. Cut and fill structures are evident in these lenses.

Interpretation

Silts and muds indicate deposition in standing water or under very low flow regimes. Very thick-bedded massive deposits of this type are indicative of overbank floodplain sedimentation (Collinson, 1978; Miall, 1978; Walker and

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Cant, 1984) and probably accumulated in short-lived ponds and lakes adjacent to stream channels. The association of montmorillonite (Richard, 1966) with unaltered and devitrified glass in these units suggests that the montmorillonite was altered elsewhere and transported to the depositional site where it was mixed with primary airfall ash. This interpretation was developed in the Jefferson River and Three Forks basins for similar deposits (Robinson, 1963; Axelrod, 1984) and appears to explain this association in the North Boulder River basin. Siltstones composed almost entirely of devitrified glass probably represent slightly reworked airfall ash that fell on or near the floodplain.

The grain size and cross-bedding of conglomerates and sandstones indicates high-energy fluvial processes (Visher, 1972). General physical characters suggest these are stream channel or point bar deposits that formed from sand bar migration and channel-fill processes. Stream channel and point bar deposits are characterized by upward cycles consisting of basal erosion, lag deposits, inclined or horizontal discontinuous stratificaton, trough cross-bedding, and micro-cross-bedding (Picard and High, 1973). Fining-upward sequences exhibited by conglomerates-coarse sands are similar to this description. Admixing of altered volcanic ash occurred during fluvial deposition.

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Clast composition of conglomerates suggests a volcanic-granitic source area. This particular combination is found northwest of the study area, but transport from another direction cannot be ruled out. The white, nearly pure pumice conglomerates probably represent fresh volcanic material that was incorporated into the stream system directly after major volcanic events.

On a larger scale, a high sinuosity alluvial plain stream system (central basin-fill facies) is suggested by these interbedded deposits. High sinuosity streams favor the preservation of extensive overbank deposits (Collinson, 1978; Cant, 1982; Walker and Cant, 1984). Braided streams rarely preserve extensive floodplain deposits (Cant, 1982). Also, laterally continuous thick silts and muds suggest a low relief depositional surface. Fining-upward sequences exhibited by conglomerates-coarse sands are consistent with a high-sinuosity stream model (Collinson, 1978) and may represent point bar deposits.

RENOVA FORMATION--DUNBAR CREEK MEMBER

Introduction

This part of the Renova Formation was described in the Jefferson River basin and is composed primarily of vitric siltstone with locally abundant arkose and conglomerate lenses (Kuenzi and Fields, 1971). In the

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Jefferson River basin the Dunbar Creek Member is Orellan in age (Kuenzi and Fields, 1971) (Figure 2).

In the North Boulder River basin, strata assignable to the Dunbar Creek Member are Chadronian in age (Figure 2). Tuffaceous (vitric) siltstone (Ts_1) dominate this member in the North Boulder River basin. This is the main basis for its designation as the Dunbar Creek Member.

Description

Strata assignable to the Dunbar Creek Member are exposed north and east of Red Hill (Figure 3). Exposures are generally poor and widely scattered, but in the Red Hill and Conrow Creek areas, outcrops are good and interpretations of vertical and lateral relationships between rock types are possible. The Dunbar Creek Member is approximately 200 m thick.

Vertebrate fossils also indicate a Chadronian age for the Dunbar Creek Member. The Climbing Arrow Member and the Dunbar Creek Member thus appear to represent two co-existing lateral facies that interfinger roughly in the present location of the North Boulder River (Figure 3). However, late Tertiary structural complications (Chapter 4) and unavoidable inaccuracies in biostratigraphic correlation make this interpretation tenuous.

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Interbedded vitric (devitrified glass) siltstones (Ts_1) and matrix (vitric silt) supported pebble conglomerates (Tsp) characterize outcrops of this member. Lesser amounts of clast-supported pebble conglomerate (Tc_2), mudstone (Tm) and montmorillonitic siltstone (Ts_2) are exposed and may be abundant locally. The finer-grained sediments and the clast-supported pebble conglomerates are similar in compositions, texture, and geometry to those in the Climbing Arrow Member.

In the region north of Red Hill, vitric siltstones are indistinctly interbedded with unsorted conglomerate composed of subangular granitic-volcanic rock fragments supported in a matrix of vitric silt. Matrix to clast ratios vary from 10:1 (matrix:clast) to 4:1. Contacts between beds are gradational or ill-defined. Slight color differences caused by varying percentages of unaltered glass shards is used to distinguish between individual beds. Ash-dominated units commonly lack rock fragments and contain chaotically distributed sand-sized pumice and intraformational clasts composed of vitric silt.

Rarely exposed are lenses of clast-supported cobble conglomerate formed primarily of subangular Paleozoic carbonate and Elkhorn Mountain volcanic rock fragments with a matrix of sand and vitric silt. Scoured bases with lags,

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graded bedding and crude horizontal bedding are features commonly exhibited. Higher in the section and to the west side of the basin, these units are coarser, thicker, more abundant, and have rough sheetlike geometries.

Directly east of Red Hill, a cobble conglomerate composed of angular, unsorted carbonate fragments (derived from the adjacent hill) in a silt-sand matrix, rests directly on Paleozoic carbonate units. Locally this conglomerate can be clast- or matrix-supported. Red vitric siltstone (Ts_3), which contains thick lenses of coarse sands and pebbles, stratigraphically overlies the cobble conglomerate. These sands and pebbles are composed primarily of distally- transported granitic-volcanic clasts in contrast to the locally-derived carbonate cobbles found in the underlying unit. The lensoidal sands and pebbles commonly fine upward and exhibit horizontal, low-angle and trough cross-bedding. Contacts between siltstones and coarser beds are sharp. Rip-ups of red siltstone are present in some lenses. Red-colored beds grade eastward into gray-brown units of similar lithologies. The red siltstones exposed adjacent to Red Hill are not found elsewhere in the basin. Coincidentally, the clay fraction of this unit is kaolinite (Richard, 1966), which is also unique to this area.

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Interpretation

In the area north of Red Hill, matrix-supported conglomerates indicate mass-flow depositional processes. The high matrix-to-clast ratio and lack of sedimentary structure is typical of debris flows (Reineck and Singh, 1980). Ash-dominated units with pumice and intraformational clasts denote primary deposition and reworking of volcanoclastic material located upslope from flows. Lenses of locally-derived clast-supported cobble conglomerate that coarsens toward the Bull Mountain front indicate high-energy fluvial channel deposition from a carbonate-volcanic source area now exposed in the Sheep Rock area (Plate I). The wide distribution of mass-flow units (Plate I) and lenticular interbedding of fluvial conglomerate resembles both debris flow dominated fans (Gloppen and Steel, 1981) and modern distal volcanic fan facies (Vessell and Davies, 1981). Massive vitric siltstones probably represent fan-blanketing surges of airfall material (Vessell and Davies, 1981).

Fan deposits overlie and interfinger eastward with muds, silts, and conglomerates like those of the Climbing Arrow Member (Plate I). This relationship suggests fan progradation (margin basin-fill facies) eastward over alluvial plain (central basin-fill facies) sedimentation.

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Sedimentary textures and structures of deposits east of Red Hill indicate localized mass-flow mixed with fluvial depositional processes. Unstratified clast- to matrix-supported locally-derived carbonate cobbles suggests proximal viscous debris flow deposition (Nilson, 1982). The overlying cross-bedded pebble conglomerates and red vitric siltstones represent fluvial process deposition. Pebbles in these deposits suggest a granitic-volcanic source area that is now exposed directly north of the study area. Paleocurrent data (Figure 4) also indicates north-to-south transport.

The anomalous composition and color of the red siltstones is not well understood. Kaolinite is usually produced in wet climates where red laterite soils are common (Thompson et al., 1982). Grim (1953, p. 343) stated that kaolinite is the dominant clay mineral associated with iron oxides in most red lateritic soils developed on carbonate rocks. The presence of red rip-up clasts in the adjacent pebble conglomerates indicates that the red color is not a secondary alteration product. Since Red Hill is composed primarily of pre-Tertiary carbonate rocks, it seems likely that the red siltstones were deposited directly adjacent to their source, and are a direct result of erosion of a lateritic soil covering Red Hill.

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Red Tertiary siltstones are rarely exposed in the Tertiary basins of southwest Montana. These deposits may have significant climatic implications and warrant future geochemical study.

RENOVA FORMATION--NEGRO HOLLOW BEDS

Introduction

The next youngest faunal level in the North Boulder River basin is Late Arikareean (Early Miocene) in age (Figure 2). Tertiary sediments of this age form a package that is generally different from those of the Chadronian (Early Oligocene) Dunbar Creek and Climbing Arrow members, but the location of boundaries between these members and the Negro Hollow beds is arbitrary and not mappable in the field (Figure 3). In southwest Montana sedimentary packages lithologically and temporally similar to the Late Arikareean deposits in the study area have not been previously described. Therefore, these sediments are informally named the Negro Hollow beds but are temporally considered a part of the Renova Formation (Figure 2).

Tertiary sediments exposed in the North Boulder River basin are oldest to the south and youngest to the north (Figure 3). An apparent biostratigraphic gap, including all the Orellan, Whitneyan, and Early Arikareean (approximately 8 m.y.) Land Mammal ages, now exists in the

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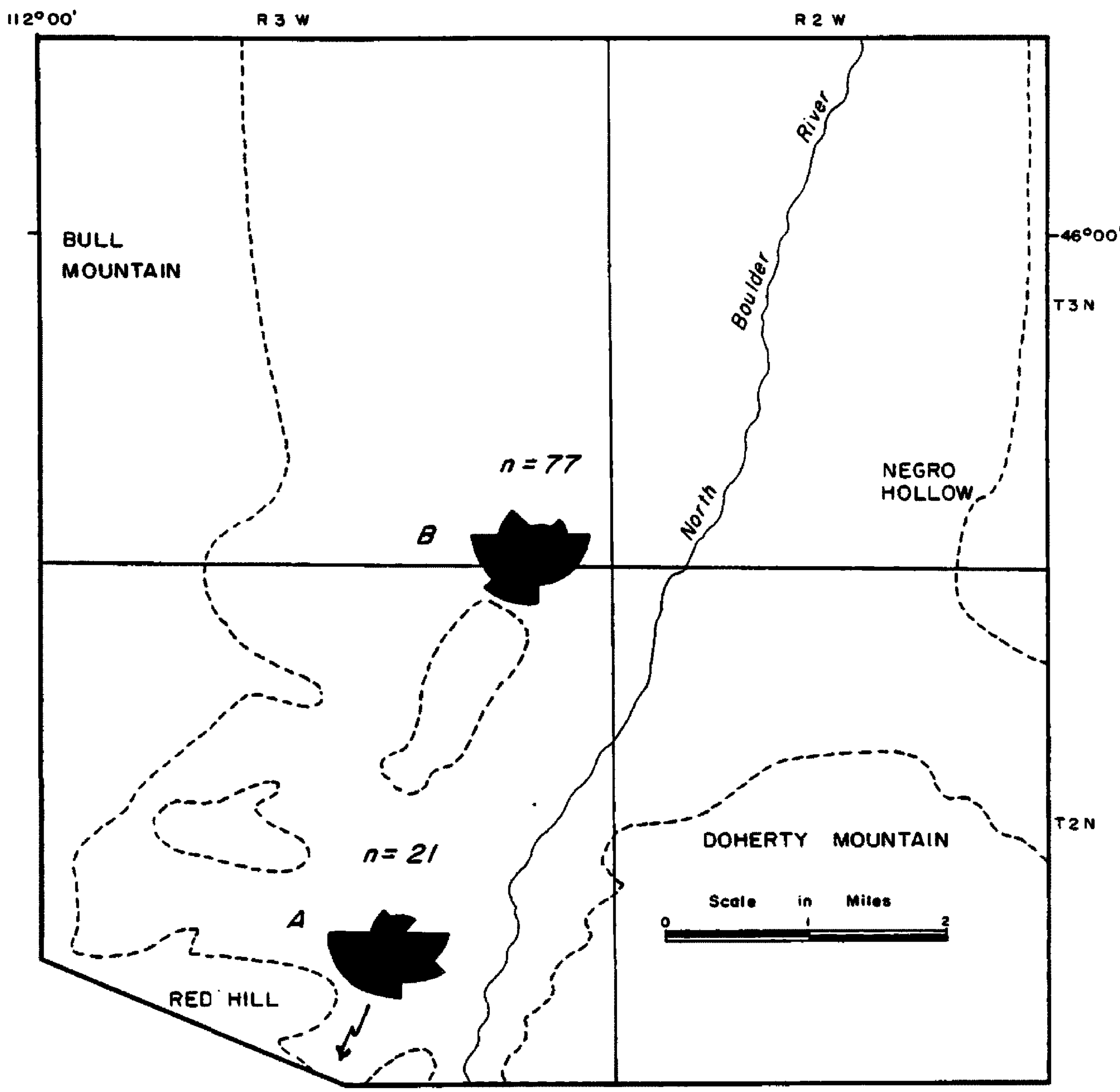

Figure 4. Rose diagrams from Renova Formation pebbles and sands; A - Chadronian , B - Late Arikareean. Shaded areas represent trough and planar cross-bed measurements. Roses are centered over or near outcrop localities.

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basin (Figure 2). Deposits of these ages should be found geographically between known Chadronian deposits to the south end of the basin and Late Arikareean localities to the north (Figure 3). Coincidentally, this area is one where Tertiary outcrops are the poorest in the entire basin (T2N, R3W, sec. 3, south half 1, 2, north half 11, 12; R2W, north half sec. 5, 6; T3N, R2W, sec. 32) (Plate I). Vertebrate fossil localities need to be established in these areas to determine whether this present biostratigraphic gap indicates an unconformity or if it is just a function of poor exposures.

Description

The Negro Hollow beds form a wide east-west trending band of exposures in the central portion of the study area (Figure 3). These sediments are fairly resistant and form more continuous outcrops than previously described Renova units. Exposures with 40 m of section and 800 meters of lateral bluffs are not uncommon. The thickness of the Negro Hollow beds is estimated to be 200 to 300 m. Vertebrate fossils are well preserved in these beds and may be abundant locally.

Matrix-supported pebble conglomerate (Tsp), similar to those infrequently exposed in the Dunbar Creek Member,

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dominate outcrops (75%) of the Negro Hollow beds. These poorly sorted conglomerates of primarily granitic clasts, with a vitric silt matrix, form very thick (2 m) to thick (.5 m) featureless beds that are laterally continuous. Twenty- to fifty-centimeter thick lenses of clast-supported pebble conglomerate (Tc_2) generally occur at the top of beds. These lenses are poorly cemented in most cases and extant vertebrates commonly burrow dens in them. The conglomerates (Tc_2) usually exhibit minor cut and fill structures or graded bedding and horizontal, low angle, and trough cross bedding. Randomly distributed intraformational clasts of the directly underlying lithology are abundant in some ash-rich beds.

Matrix-supported conglomerates (Tsp) grade laterally into or are interbedded with thin (2 cm) to (25 cm) medium tabular beds of thinly laminated vitric silt and ash. Planar cross-bedding is evident in some units. Contacts between laminated beds are usually sharp. In rare cases, beds are abruptly terminated and scoured by matrix-supported conglomerates.

A distinct central basin facies is well exposed (T2N, R3W, NE¼ sec. 2, NW¼ sec. 1) and consists of thick (.5 m) bedded, wedge to lensoidal sets of clast-

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supported pebble-cobble conglomerate that interfinger with montmorillonitic siltstones (Ts_2), mudstones (Tm), and unstratified sands (Tss). Clast composition is primarily granitic-volcanic. Conglomerates are well cemented and form small bluffs (3-4 m) that can be continuous for up to 70 meters in the best exposures (T2N, R3W, NE¼, sec. 2).

Internal stratification consists of variably bedded, multistory, horizontal to low angle and trough cross-bedded pebbles. Cross-bedding varies greatly in size, but most sets are thick (30-50 cm) with troughs approaching four meters in width and low angle slipfaces up to 3 meters long. Lensoidal scour and fill structures filled with cobbles are common in the lower half of outcrops.

Interpretation

The abundance of matrix-supported conglomerate indicates that mass-flow processes were very active during this Late Arikareean depositional pulse. These poorly-sorted pebble conglomerates are similar to debris flow deposits described and illustrated by Fisher (1971, p. 922) from the Vasquez Formation of California. Also, laterally continuous beds, thick

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bedding, and poorly defined stratification are criteria described by Bull (1972), Nilson (1982), and others, for recognizing ancient debris flow deposits. According to Bull (1977, p. 236) debris flows are promoted by steep slopes, lack of vegetation, short periods of abundant water supply, and a source providing debris with a muddy matrix. In the Late Arikareean, source area conditions conducive to debris flows were probably present partly due to the tremendous amount of altered volcanic ash in highlands as suggested by the vitric silt matrix.

Lensoidal clast-supported sands and pebbles represent channels developed on top of debris flows and indicate reworking of their upper surfaces by fluvial processes. Some of the reworking may be due to dewatering of mass-flow units upslope from these channel-fill sediments.

Laminated vitric siltstones probably represent the fines winnowed by this fluvial reworking that were deposited in ephemeral ponds or lakes (playa?). These thin tabular beds have sharp contacts and are well-sorted in contrast to the debris flow deposits indicating water-laid sedimentation (Bull, 1972). A lacustrine (playa?) environment of deposition is suggested by the dominantly thin and continuous bedding which is

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not prevalent in other continental depositional environments (Collinson, 1978). These siltstones are physically similar to the nearshore lacustrine facies of the Passamari Member from the upper Ruby River basin but lack the fossils found in the latter (Monroe, 1981). Therefore, a lacustrine depositional environment interpretation is tenuous.

Interbedded montmorillonitic siltstones, mudstones, and pebble-cobble conglomerates indicate the presence of a river system in Late Arikareean time. High-energy fluvial processes are indicated by the coarse-grained, large cross-bedded conglomerates. Large pebbly crossbed sets are formed by migration of pebbly dunes or flat-topped bars (Cant, 1982). Montmorillonitic silts and muds are probably overbank deposits associated with this river system. The bedforms and grain size are similar to those described by Miall (1977) for braided river deposits. This Late Arikareean, dominantly pebbly river system has physical characteristics that place it part way between Miall's (1977) Scott-type (gravels mainly) and Donjek-type (mostly sands, some pebbles and gravels) braided river models. Granitic-volcanic clast composition implies a source area to the north. Paleocurrent data also indicates north-to-south transport (Figure 4).

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MIDDLE TERTIARY UNCONFORMITY

Introduction

The Renova Formation and the Six Mile Creek Formation are separated by an erosional and/or angular unconformity (Fields and others, 1985). This unconformity has been mapped regionally in southwest Montana (Robinson, 1960; Kuenzi and Richard, 1969; Kuenzi and Fields, 1971; Rasmussen, 1973; Monroe, 1976; and others). Most studies thus far completed in southwestern Montana basins indicate the presence of this unconformity, although the duration of the hiatus as expressed by the preserved strata varies considerably but always includes the Hemingfordian Land Mammal Age (Fields and others, 1985) (Figure 2).

However, recent detailed lithostratigraphic mapping in the Jefferson River basin questions the presence of the unconformity in central areas of the basin (Axelrod, 1984). According to Axelrod (1984), central basin facies show little or no structural or lithological discontinuity across the unconformity. Axelrod (1984) accepts the presence of an angular unconformity in certain basin margin locations but suggests an apparent time gap in basin margin areas may be related to local tectonic uplifts only, deposition could still be

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occurring in central basin areas at the same time. The North Boulder River basin is an ideal location to test this hypothesis because it is basically a north-eastern extension of the Jefferson River basin and was also mapped by lithofacies (this report).

<u>Description</u>

The unconformity in the North Boulder River basin is expressed quite differently on the west side of the basin than on the east side. Lithologically the unconformity is not mappable on the west side. Late Arikareean and Early Barstovian strata both contain abundant debris flow deposits (Tsp). Many debris flow deposits dated as Early Barstovian are physically identical to similar Late Arikareean deposits located high in the Renova Formation section at Cottonwood Creek (MV8423) (Plate I). If an angular or erosional unconformity exists, it apparently is not exposed. From a purely sedimentological point of view the transition from Late Arikareean to Early Barstovian sedimentation appears to represent a coarsening upward sequence caused by uplifts in the Bull Mountain area resulting in the progradation eastward of coarse-grained alluvial fan deposits. Therefore, the location of the unconformity

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in the west part of the basin has to be arbitrarily placed between the highest Late Arikareean and lowest Early Barstovian deposits, somewhere in the vicinity of sec. 26, 25, and 19, T3N, R3W (Plate I).

On the east side of the basin the unconformity can be reasonably located in the southern half of sec. 28, T3N, R2W. In this area, Late Arikareean (MV5907) and Early Barstovian (MV8411) deposits are separated by 20 m of section (Plate I). Also, in this area Late Arikareean and Early Barstovian deposits are lithologically distinct but nowhere are they exposed in contact with each other. If the contact is angular, it is not apparent and surely is no greater than 5 degrees. Also, structural complications cloud relationships (Plate I). Therefore, the unconformity cannot be exactly mapped in the east margin area, but can be approximately located within 20 m of section.

Interpretation

The location of the east basin margin unconformity may be the case Axelrod (1984) alluded to. This hypothesis would suggest tectonic uplift of the area east of Negro Hollow caused localized non-deposition or erosion which would account for an apparent unconformity

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here. Meanwhile, deposition could still be occurring in a central basin facies to the west of Negro Hollow. Early Barstovian central basin facies are not exposed in the North Boulder River basin so their relationship to Late Arikareean deposits are not discernible. Therefore, this hypothesis is unfortunately not testable.

The difficulty in mapping the unconformity in the west side of the basin may suggest it does not exist in the North Boulder River basin. However, I suggest caution in this interpretation. It is difficult to ignore that, in nearly 100 years of vertebrate fossil collection in the Tertiary basins of southwest Montana, not once has a distinct Hemingfordian fauna been reported (Fields and others, 1985). In the North Boulder River basin a Hemingfordian fauna was not located anywhere in the basin, even though Late Arikareean and Early Barstovian outcrops are good and locally fossiliferous. Therefore, I interpret that this apparent biostratigraphic gap represents a significant non-depositional hiatus in the North Boulder River basin and should be recognized as an erosional unconformity (Figure 2).

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SIX MILE CREEK FORMATION

Introduction

The Six Mile Creek Formation was first described in the Toston Quadrangle, Gallatin County, Montana (Robinson, 1967). It is composed primarily of coarse-grained material (fine sand and coarser) (Kuenzi and Fields, 1971). Conglomerate is characteristic of this formation (Kuenzi and Fields, 1971). The Six Mile Creek Formation is Barstovian to Hemphillian in age (Fields and others, 1985).

In the North Boulder River basin, the Six Mile Creek Formation overlies the Renova Formation with erosional unconformity. The Six Mile Creek Formation is characterized by matrix- (Tsp) and clast-supported (Tc_3 and Tc_4) conglomerates. Strata assignable to this formation are exposed in the northern portion of the study area (Figure 3). These deposits contain abundant vertebrate fossils of Early Barstovian age (Figure 2). The Six Mile Creek Formation is roughly 400 m thick in the North Boulder River basin.

Description

Six Mile Creek Formation strata are more resistant and coarser grained than any previously described deposits in this report and can form extensive outcrops of small

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cliffs and bluffs. This formation is composed of a sequence of beds that vary greatly in grain size, sorting, and thickness. Clast composition of conglomerates follows a pattern that is geographically subdivided by the North Boulder River. Outcrops west of the river contain clasts of Cretaceous Elkhorn Mountain volcanics and those east of the river contain Paleozoic carbonate rock fragments and an occasional clast derived from the North Doherty intrusive complex (Plate I). Conglomerates are matrix- or clast-supported with mixtures of the two common in outcrops.

Matrix-supported units are poorly sorted, thick (1-2 m), laterally continuous, and contain randomly distributed angular to subrounded pebbles, cobbles, boulders, and intraformational clasts in a matrix of vitric silt and sand. In rare cases, crude inverse grading is present.

Clast-supported units are tabular to lensoidal, moderately sorted, and contain subangular to subrounded pebbles, cobbles, and rare boulders. Imbricated clasts are abundant locally. These deposits commonly form deeply entrenched cut-and-fill structures in underlying strata and are most frequently exposed near the basin margins. Lensoidal channels are backfilled with crudely

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horizontal, low angle, and trough cross-bedded coarse sands, pebbles, and cobbles.

Finer grained units composed primarily of well to moderately sorted sand and pebbles usually form medium beds with poorly defined horizontal and trough cross-bedding or are massive. In general these beds exhibit sheet-like geometries with grain size increasing toward basin margins.

Interpretation

The Six Mile Creek Formation was deposited by an alluvial fan system. Matrix-supported units were deposited by mass-flow processes and represent debris flows derived from local source areas in the Bull Mountain and Negro Hollow areas. Lensoidal clast-supported conglomerates are channels that were temporarily entrenched into the fan and later refilled by fluvial processes. Moderately sorted, medium (20 cm) bedded, sheet-like finer grained units probably represent sheetflood deposits formed by surges of sediment-laden water that spread out from the end of a stream channel on a fan. Interbedded deposits of the above are indicative of alluvial fan sedimentation (Blissenbach, 1954; Bull, 1972; Reineck and Singh, 1980; Nilson, 1982; Rust and Koster, 1984).

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Clast composition indicates source areas of alluvium directly east, west, and south of the depositional sites. Paleochannel data supports this interpretation (Figure 5). Also, these sediments record the unroofing of the North Doherty intrusive complex and the first exposure of the extensive Paleozoic carbonate outcrops that now form the east basin boundary (Plate I). Faulting was undoubtedly active at this time with highlands rising rapidly and shedding detritus into the basin by way of alluvial fans.

Early Barstovian Six Mile Creek strata are the youngest exposed Tertiary sediments in the North Boulder River basin. They are unconformably overlain by unconsolidated gravels of probable Pleistocene age.

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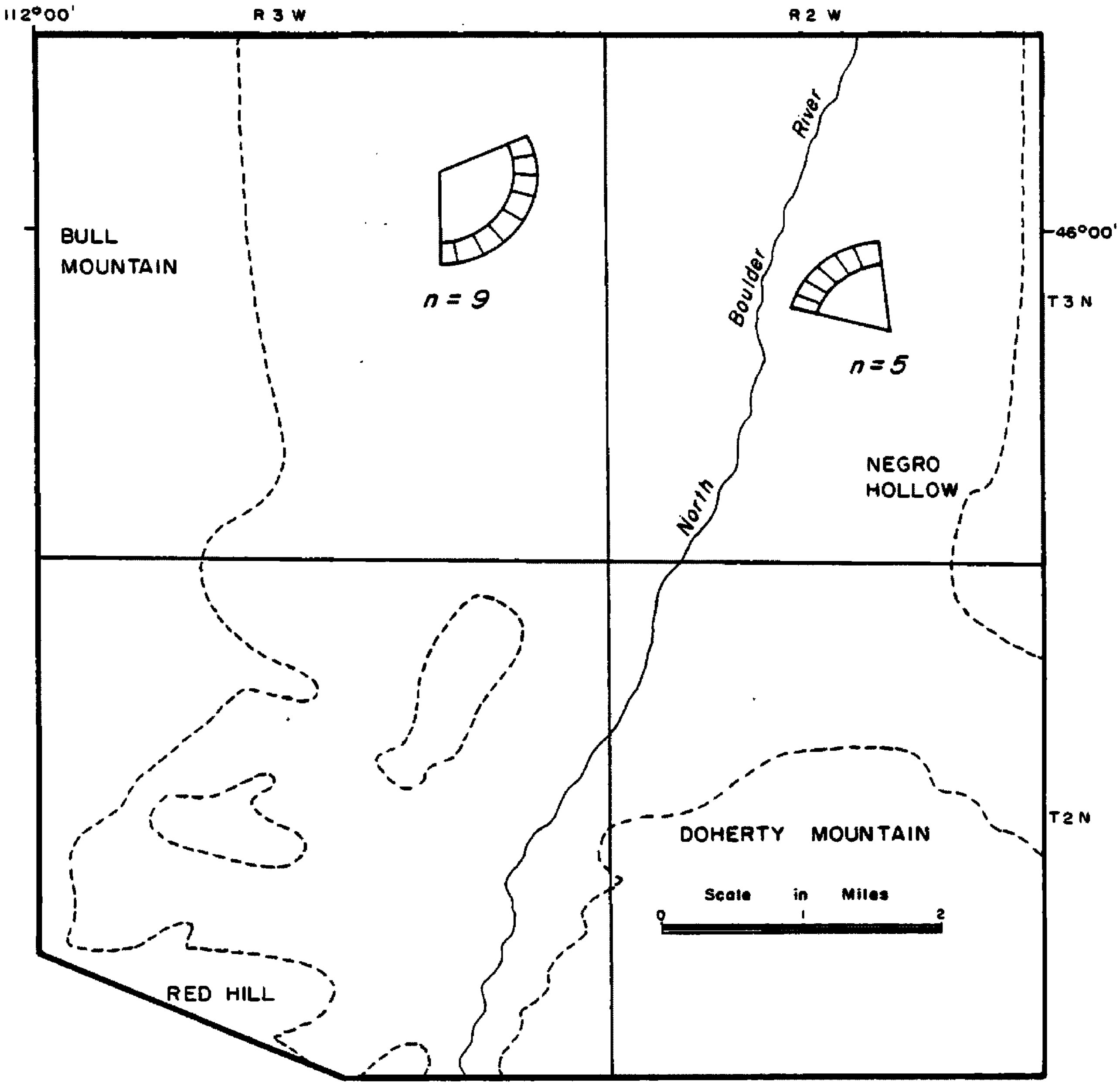

Figure 5. Rose diagrams from Six Mile Creek Formation paleochannels. Striped arcs designate ranges of paleochannels and the direction of flow which created the channels. Roses are centered over outcrop localities.

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CHAPTER 4

STRUCTURE

Description

Tertiary beds east of the North Boulder River generally dip east into a major basin-bounding normal fault termed the Starretts Ditch fault (Aram, 1979) (Figure 6). The expressed contact between Tertiary and pre-Tertiary strata along this fault is strictly linear in nature. Pardee (1950) first recognized this fault using physiographic evidence west of Doherty Mountain and estimated a vertical throw of 350 m or more between Tertiary and pre-Tertiary rocks. Reconnaissance geologic mapping by Aram (1979) extended this fault northward to Negro Hollow. Recent detailed geologic mapping (this report) supports these interpretations on the location of this fault.

South of Negro Hollow, along the flanks of Doherty Mountain Chadronian (Climbing Arrow Member) sediments are juxtaposed against Precambrian and Paleozoic sedimentary rocks along a fairly well-delineated scarp (Plate I). Tertiary rocks exposed along or near this fault trace generally dip 10-35° to the east into the fault. The abrupt rise in elevation (600 m) of Doherty Mountain above the basin floor suggests an offset in the hundreds of meters along the Starretts Ditch fault in this area.

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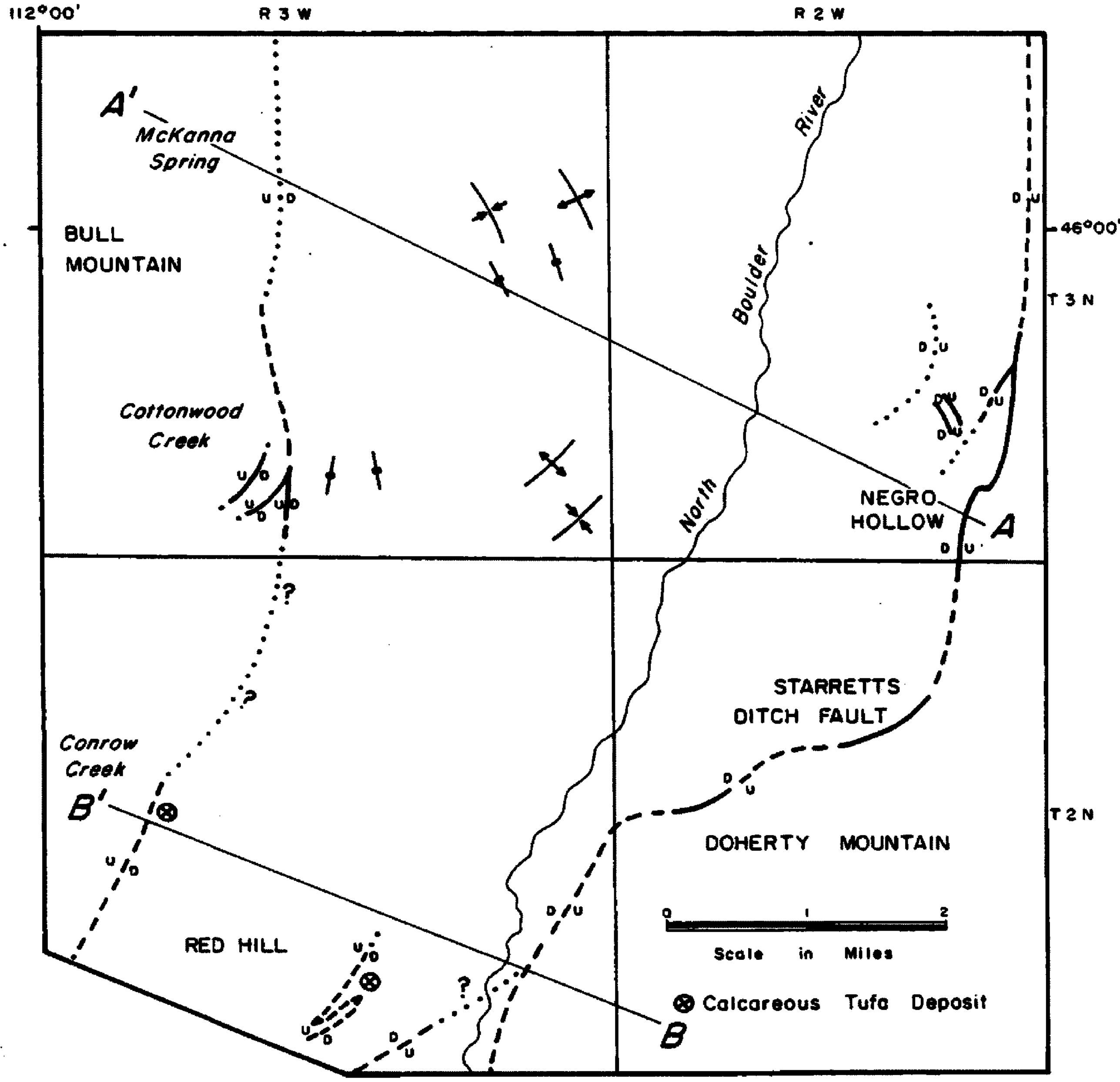

Figure 6. Tectonic map of the southern half of the North Boulder River basin showing the location of folds and faults.

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Further north at Negro Hollow the location of the Starretts Ditch fault is clearly defined by a scarp which is dramatically accented by a nearly vertical wall of Mississippian limestone (Figures 6 and 7). This well-exposed fault scarp dips 70° to the west and rises 150 m above the basin floor, suggesting an offset in the hundreds of meters. A series of minor faults within the Tertiary section are exposed west of the main fault in this area (Figure 6). Stratigraphic-paleontological relationships suggest that these faults have minor offsets (tens of meters or less). Bedding attitudes of Tertiary rocks within 500 m west of the main fault scarp generally have a northwest dip component of 5-15°. Strata further west have eastward dips of 5-15° and are similar in attitude to Tertiary beds north of Doherty Mountain.

The west basin-bounding faults lack dramatic scarps and are difficult to map. This suggests offsets are minor and probably are no greater than the tens of meters range. Also, Tertiary sediments onlap onto bedrock along the west margin of the basin (Plate I). In instances where these onlapping sediments are in contact with mappable faults (Cottonwood Creek), sedimentation patterns are not disrupted by fault movements, which suggests minor displacements (see Basin Development Section for further discussion).

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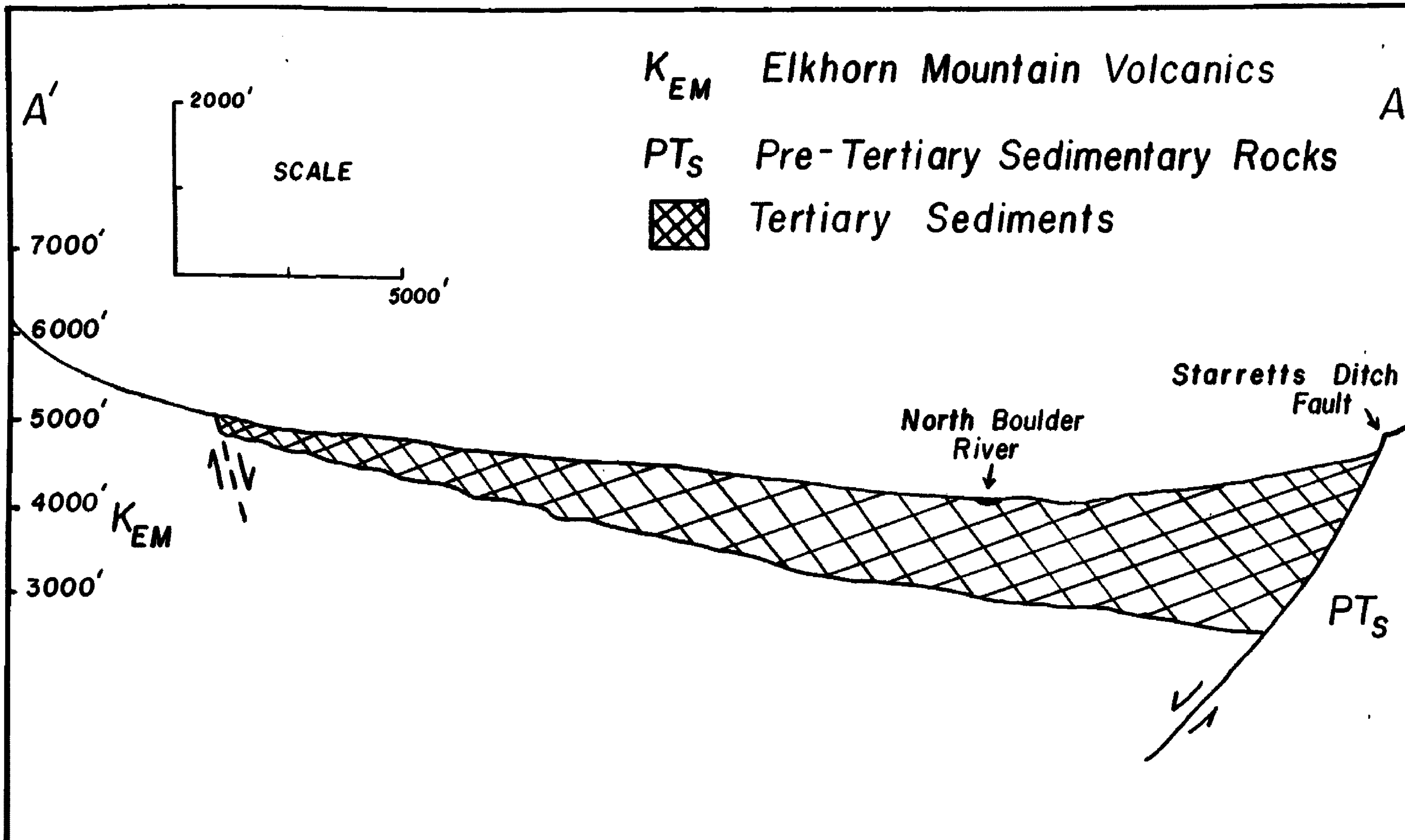

Figure 7 Suggested geologic cross section of the North Boulder River basin along A'- A. (For section location see Figure 6 or Plate I).

In the McKanna Spring area probable Plio-Pleistocene-aged pedimentation has concealed the location of the fault scarp(s). Further south at Cottonwood Creek basin-bounding structure is expressed as a system of small faults (Figure 6). In this area folded remnants of Tertiary deposits lie on Elkhorn Mountain volcanics. Slickensides are locally developed on exposures of the volcanics and suggest a relative west up-movement. A series of joint swarms and broad anticlines and synclines which subparallel the fault trace are located to the east-northeast (Figure 6).

South of Cottonwood Creek the Tertiary-pre-Tertiary contact becomes very irregular and insulbergs of pre-Tertiary rocks stand in relief in the central floor of the basin. This is probably the pre-basin-fill erosional surface being exhumed by present-day erosion. Tertiary outcrops are poor, bedding attitudes vary greatly, and faults are difficult to locate. One mappable fault occurs near Conrow Creek (Figure 6). Tertiary rocks dip up to 10° west into the fault and the relative movement has isolated a body of Elkhorn Mountain volcanics from the main outcrops (Figure 8). Coincidentally, a calcareous tufa deposit is located along the fault trace. Hot springs deposits are commonly associated with faults (Monroe, 1976; Reynolds, 1979).

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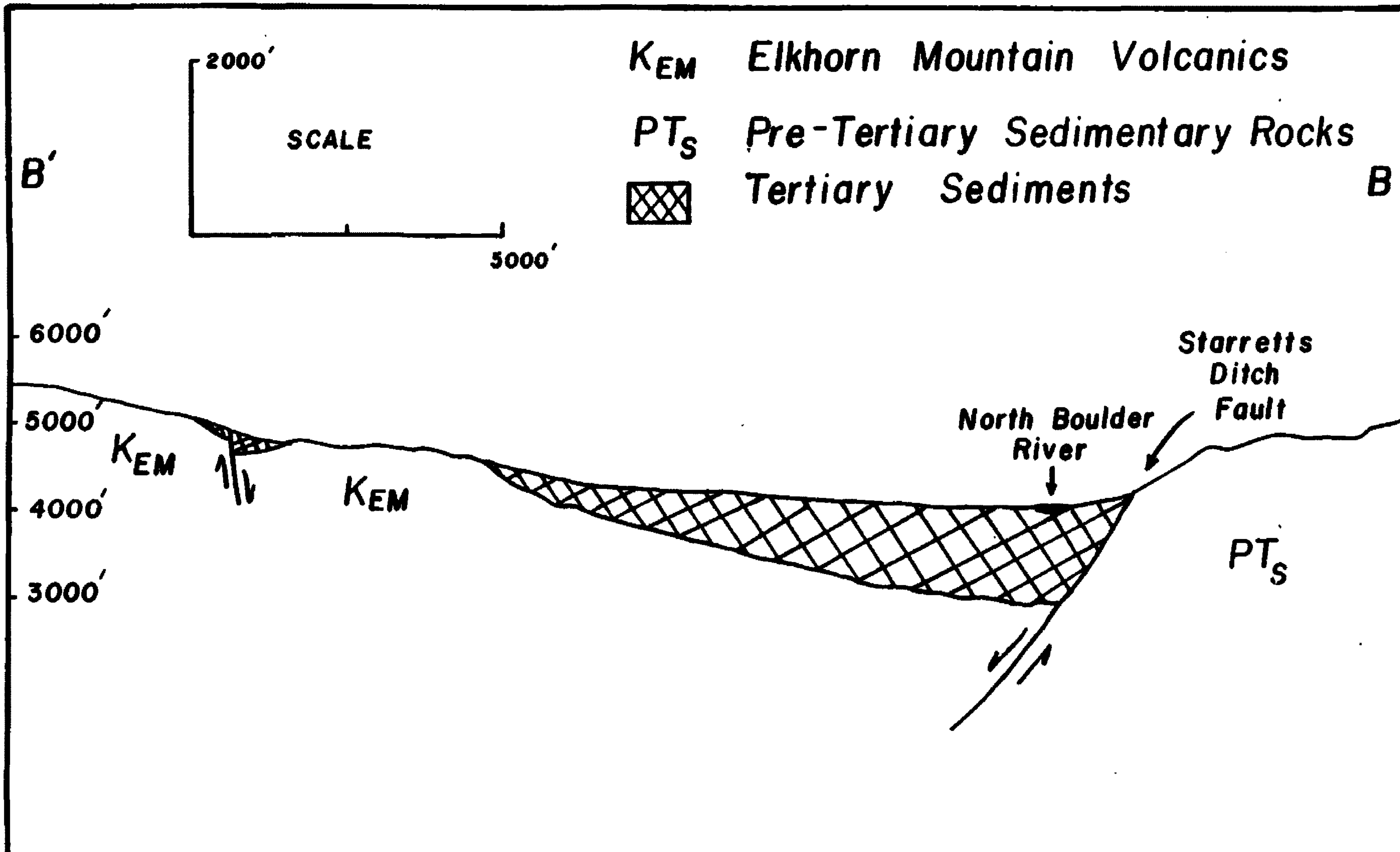

Figure 8 Suggested geologic cross section of the North Boulder River basin along B′-B. (For section location see Figure 6 or Plate I).

Slickensided and steeply dipping (up to 53°) Tertiary rocks are exposed east of Red Hill in the southernmost part of the study area (Plate I). Immediately adjacent to Red Hill is a series of small east- and west-dipping normal faults that are best described as a small horst and graben structure (Figure 6). A calcareous tufa deposit is also associated with this structure.

Interpretation

The present outline of the North Boulder River basin is most likely the result of breakup and eastward rotation (east down) of the pre-Tertiary basement during basin subsidence (Figures 7 and 8). Major downdropping along the steeply west-dipping Starretts Ditch fault is suggested by the development of the large scarps exposed along the fault trace and by the generally eastward-dipping Tertiary strata east of the North Boulder River. Tertiary strata rotated into basin-bounding faults are similar to one-sided basin and range structures described by Anderson and others (1983). Rotation of this type is best interpreted geometrically as the result of listric normal faulting (Reynolds, 1979; Stewart, 1980; Anderson and others, 1983).

The listric normal fault model is further supported by seismic and gravity studies investigating the depth

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of the Tertiary basin fill in the North Boulder River basin. The results of these studies indicate a maximum depth (500 m) of basin fill located near the east basin margin with the thickness of Tertiary deposits progressively diminishing westward (Parker, 1961; Nelson, 1962; Wilson, 1962; Richard, 1966). This compares favorably with the listric fault model developed by Reynolds (1979) for the Townsend and Helena valleys of southwest Montana. According to this study (Reynolds, 1979) the maximum depth of basin fill is located near the downdropped and rotated listric fault block and thins in the opposite direction. Seismic and gravity surveys indicate a similar basin fill depth profile in the North Boulder River basin (Figures 7 and 8).

The minor faults exposed within the Tertiary strata north of Negro Hollow probably represent antithetic faults developed within the subsiding pre-Tertiary basement. Small faults of this type can develop in association with listric normal faults (Hamblin, 1965; Proffett, 1977), and have dip directions geometrically opposite to the main fault. The presence of antithetic faults north of Negro Hollow is suggested by the anomalous northwest-dipping strata, which probably indicates fault block rotation opposite to that of the main fault (east-dipping beds).

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Faults, joints, and broad folds on the western side of the basin are most likely local adjustments that formed to relieve stresses developed during basin subsidence. Pre-Tertiary basement block rotation may have contributed to these stresses.

Basin Development

The timing and processes related to the origin of the North Boulder River basin are obscure. Regional studies suggest that intra-arc extension and basin formation related to Laramide convergence began by middle Eocene time (Fields and others, 1985). This structural style combined with Eocene erosion is interpreted to have delineated early basin margins. How these processes affected the North Boulder River basin is unclear. Initial basin development is indicated by preservation of early Oligocene sediments and was probably due to late Eocene faulting and/or erosion.

In contrast to initial origin, basin development through later Tertiary time can be deciphered and is best understood by interpretation of sedimentation patterns and their relationships with mapped Tertiary structures. Distribution of sediment types developed during deposition of the Renova Formation (Chadronian-Late Arikareean) suggests that the North Boulder River basin was once

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the western part of a broader alluvial plain that extended generally eastward. Lithotypes generally referable to the Dunbar Creek Member (Chadronian) are interpreted to represent a basin margin depositional facies with highlands located to the west (see Chapter 3). Sediments of the Climbing Arrow Member (Chadronian) are generally time-equivalent to those of the Dunbar Creek Member and are interpreted to represent a central basin facies (see Chapter 3). Therefore, Chadronian-aged sedimentation relationships indicate a west-to-east depositional pattern (Figure 3). This trend spatially suggests that a basin margin facies was being deposited during Chadronian time somewhere to the east of the present confines of the North Boulder River basin. The North Boulder River basin was probably connected to the Three Forks basin at this time (Thompson and others, 1981). The Chadronian depositional trend is now abruptly terminated by the upthrown block of the Starretts Ditch fault.

The Negro Hollow beds (Late Arikareean) record a similar depositional pattern, although this is not as clear as earlier sedimentation trends. Late Arikareean sediments indicate a location of the west basin margin similar to that in the earlier sequence with highlands to the west-northwest (see Chapter 3). In contrast to the Chadronian-aged pattern, central and basin margin

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facies are complexly interbedded and there isn't a clear-cut west-to-east lateral relationship evident (Plate I). Significant, though, is the fact that outcrops now forming the present east basin margin are composed primarily of Paleozoic carbonates. The rocks comprising the coarse fraction of the Negro Hollow beds totally lack carbonate clasts. This, along with the crude west-to-east sedimentation pattern, questionably suggests that the east basin margin was located further east during Late Arikareean time.

The timing of major uplifts disrupting Renova Formation deposition patterns is indicated by Six Mile Creek (Early Barstovian) sedimentation. Clast composition of these primarily coarse-grained alluvial fan deposits (see Chapter 3) indicate proximal basin source areas in the uplifted Bull Mountain and Negro Hollow-Doherty Mountain areas. Sedimentation patterns for the first time denote a west transport component of sediment (Figure 5). These Early Barstovian-aged uplifts truncated the eastward--draining alluvial plain that had existed throughout Chadronian-Late Arikareean time.

There is difficulty in documenting the timing of post-Barstovian structural events in the North Boulder River basin because of the lack of sediment preservation for this time. Regional studies generally indicate that

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Barstovian uplifts continued into late Miocene or early Pliocene time (Reynolds, 1979; Fields and others, 1985). Sometime between this time interval and the regional development of late Pliocene or early Pleistocene pediments (Fields and others, 1985), significant regional extensional stresses (Reynolds, 1979) resulted in major block-fault movements as the North Boulder River basin subsided. Listric normal faults accommodated block subsidence and the Tertiary section was rotated into the Starretts Ditch fault at this time.

Late Pleistocene to recent structural movements are not evident in the North Boulder River basin. Late Pliocene or early Pleistocene pediments (Fields and others, 1985) are undisturbed and evidence for the development of any post-Pleistocene fault scarps is lacking.

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CHAPTER 5

GEOLOGIC HISTORY

The timing and processes related to the origin of the North Boulder River basin are obscure. Regional studies suggest that structural and erosional evolution of the Tertiary basins of southwest Montana began by middle Eocene time (Fields and others, 1985). Initial development of the North Boulder River basin is indicated by preservation of early Oligocene (Chadronian) sediments and was probably the result of late Eocene faulting and/or erosion.

Chadronian sediments reflect mixed mass-flow and fluvial-floodplain deposition in a generally southeastern draining alluvial plain. Sediment grain size suggests topographic relief was low. Primary and altered ash and significant other volcanoclastic materials were deposited directly or were being reworked into the basin from adjacent highlands. Local source areas in the Red Hill region were actively contributing sediment to the alluvial site. The North Boulder River basin was probably connected to the Three Forks basin at this time (Thompson and others, 1981).

Orellan, Whitneyan, and Early Arikareean aged sediments were not located in the North Boulder River basin. This is probably related in part to poor exposures.

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Late Arikareean sediments indicate predominantly mass-flow with lesser fluvial and lacustrine(?) deposition. Significant accumulations of altered ash in adjacent highlands probably make conditions conducive to debris flows. Reworked mass-flows, fluvial, and minor lacustrine (?) deposits constituted central basin facies. Southeastern drainage patterns were probably still present at this time.

In Hemingfordian time a depositional hiatus probably occurred throughout southwest Montana (Fields and others, 1985). This nondepositional event is interpreted to be the result of regionally synchronous climatic events (Thompson and others, 1982). A major regional unconformity marks this episode and has been identified in a number of intermontane basins (Fields and others, 1985). In the North Boulder River basin, the presence of the unconformity is indicated by a biostratigraphic gap encompassing all of the Hemingfordian Land Mammal Age and is expressed erosionally.

Barstovian sediments are the youngest temporally recognizable Tertiary strata in the North Boulder River basin and reflect a change to predominantly coarser-grained alluvial fan deposition. Uplifts centered in the Bull Mountain and Negro Hollow-Doherty Mountain areas began shedding detritus and contributed to the progradation of

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alluvial fans into the basin. The southeastward draining depositional plain that probably existed throughout Chadronian to Late Arikareean time was truncated by Negro Hollow-Doherty Mountain uplifts. The basin in its present form was probably delineated by this time.

Uplifts that are evident in Barstovian time probably continued into late Miocene or early Pliocene time (Reynolds, 1979; Fields and others, 1985). Sometime between this time interval and the regional development of late Pliocene or early Pleistocene pediments (Fields and others, 1985), regional extensional stresses resulted in major block-fault displacement as the North Boulder River basin subsided. Listric normal faults accommodated block subsidence and the Tertiary section was rotated into the Starretts Ditch fault.

Pleistocene gravels cap pediments in the North Boulder River basin. Any recent faulting was probably minor and is not evident.

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LIST OF REFERENCES

Alexander, R. G., Jr., 1955: Geology of the Whitehall area, Montana: Yellowstone-Bighorn Research Project Contr. 195, 111 p.

Anderson, E. R., Zoback, M., and Thompson, G. A., 1983: Implications of selected sub-surface data on the structural form and evolution of some basins in the northern basin and range province, Nevada and Utah. Geol. Soc. Amer. Bull., v. 94, pp. 1055-1072.

Axelrod, R. B., 1984: Tertiary sedimentary facies, depositional environments, and structure, Jefferson basin, southwestern Montana. M.S. thesis, University of Montana, Missoula, Montana, 64 p.

Aram, R. B., 1979: Cenozoic geomorphic history relating to Lewis and Clark Caverns, Montana. M.S. thesis, Montana State University, Bozeman, Montana, 150 p.

Blissenbach, E., 1954: Geology of alluvial fans in semiarid regions. Geol. Soc. Amer. Bull., v. 65, pp. 175-190.

Brenner, E. F., and Glanzman, R. K., 1979: Tertiary sediments in the Lake Mead area, Nevada, In Newman, G. W., and Goode, H. D., eds., Basin and Range Symposium, Rocky Mt. Assoc. Geol., and Utah Geol. Assoc., pp. 313-323.

Bull, W. B., 1972: Recognition of alluvial fan deposits in the stratigraphic record, In Rigby, J. K., and Hamblin, W. K., eds., Recognition of Ancient Sedimentary Environments. S.E.P.M. Spec. Pub. 16, pp. 63-83.

____________, 1977: The alluvial fan environment. Progress in Physical Geography, v. 1, pp. 222-270.

Burfeind, W. J., 1967: A gravity investigation of the Tobacco Root Mountains, Jefferson Basin, Boulder Batholith, and adjacent areas of southwestern Montana. Ph.D. dissertation, Indiana University, Bloomington, Indiana, 146 p.

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Cant, D. J., 1982: Fluvial facies models and their application. In Scholle, P. A., and Spearing, D. R., eds., Sandstone depositional environments. Amer. Assoc. Pet. Geol., Memoir 31, pp. 115-137.

Clark, J., 1941: An anaptomorphid primate from the Oligocene of Montana. Jour. Paleo., v. 15, no. 5, pp. 562-563.

Collinson, J. D., 1978: Alluvial sediments, Lakes. In Reading, H. G., ed., Sedimentary environments and facies. Oxford, Blackwell Scientific Publ., pp. 15-79.

Crandell, D. R., 1971: Postglacial lahars from Mount Rainier volcano, Washington. U. S. Geol. Survey Prof. Paper 677, 73 p.

Douglass, E., 1903: New vertebrates from the Montana Tertiary. Carn. Mus. Ann., v. 2, pp. 145-199.

Downs, T., 1956: The Mascall fauna from the Miocene of Oregon. Univ. Calif. Publ. Geol. Sci., v. 31, pp. 199-354.

Fields, R. W., ed., 1958: Guidebook, Eighth Field Conference, Society of Vertebrate Paleontology, Western Montana. Montana State University Press, Missoula, 65 p.

Fields, R. W., Rasmussen, D. L., Tabrum, A. R., and Nichols, R., 1985: Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho: A summary. In Cenozoic Paleogeography of the west-central United States, Rocky Mountain Paleogeography Symposium 3, Rocky Mtn. Section, S.E.P.M.

Fisher, R. V., 1971: Features of coarse-grained, high concentration fluids and their deposits. Jour. Sed. Pet., v. 41, pp. 916-927.

Gidley, J. W., 1907: Revision of the Miocene and Pliocene Equidae of North America. Bull. Am. Mus. Nat. Hist., v. 23, pp. 865-934.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Gloppen, T. G., and Steel, R. J., 1981: The deposits, internal structure and geometry in six alluvial fan-fan delta bodies (Devonian-Norway), a study in the significance of bedding sequence in conglomerates. In Ethridge, F. G., and Flores, R. M., eds., Recent and Ancient Nonmarine Depositional Environments, Models for Exploration. Soc. Econ. Paleo. Min. Spec. Publ. 31, pp. 49-69.

Green, M., 1958: Arikareean rhinoceroses from South Dakota. Jour. Paleo., v. 32, no. 3, pp. 587-594.

Grim, R. E., 1953: Clay mineralogy. McGraw-Hill Book Co., Inc., New York, N. Y., 384 p.

Hamblin, W. K., 1965: Origin of "Reverse Drag" on the downthrown side of normal faults. Geol. Soc. Amer. Bull., v. 76, pp. 1145-1164.

Henshaw, P. C., 1942: A Tertiary mammalian fauna from the San Antonio Mountains near Tonopah, Nevada. Carn. Inst. Wash. Publ., no. 530, pp. 77-168.

Hoffman, D. S., 1971: Tertiary stratigraphy, vertebrate paleontology, and paleoecology of a portion of the Lower Beaverhead River basin, Madison and Beaverhead Counties, Montana. Ph.D. dissertation, University of Montana, Missoula, Montana, 153 p.

Klepper, M. R., Weeks, R. A., and Ruppel, E. T., 1957: Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U. S. Geol. Survey Prof. Paper 292, 82 p.

Koerner, H. E., 1939: The geology and vertebrate paleontology of the Fort Logan and Deep River formations of Montana. Ph.D. dissertation, Yale University, 141 p.

Kuenzi, W. D., 1966: Tertiary stratigraphy in the Jefferson River basin, Montana. Ph.D. dissertation, University of Montana, Missoula, Montana, 293 p.

Kuenzi, W. D., and Richard, B. H., 1969: Middle Tertiary unconformity, North Boulder and Jefferson basins, southwestern Montana. Geol. Soc. Amer. Bull., v. 80, pp. 315-320.

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Kuenzi, W. D., and Fields, R. W., 1971: Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana. Geol. Soc. Amer. Bull., v. 82, pp. 3373-3394.

Lander, E. B., 1977: A review of the Oreodonta (Mammalia, Artiodactyla), Parts I, II, and III. Ph.D. dissertation, University of California-Berkeley, Berkeley, California, 474 p.

Lillegraven, J. A., McKenna, M. C., and Krishtalka, L., 1981: Evolutionary relationships of middle Eocene and younger species of Centetodon (Mammalia, Insectivora, Geolabididae) with a description of the dentition of Ankylodon (Adapisoridae). University of Wyoming Publications, v. 45, 113 p.

Macdonald, J. R., 1956: The North American anthracotheres: Jour. Paleo., v. 30, no. 3, pp. 615-645.

________________, 1963: The Miocene faunas from the Wounded Knee area of western South Dakota. Bull. Am. Mus. Nat. Hist., v. 125, art. 3, pp. 139-238.

________________, 1966: The Barstovian Camp Creek fauna from Elko County, Nevada. Con. in Sci., Los Angeles Co. Mus., no. 92, pp. 1-18.

Matthew, W. D., 1924: Third contribution to the Snake Creek fauna. Bull. Am. Mus. Nat. Hist., v. 50, pp. 59-210.

Matthew, W. D., and Cook, H. J., 1909: A Pliocene fauna from western Nebraska. Bull. Am. Mus. Nat. Hist., v. 26, pp. 361-414.

McGrew, P. O., 1941: The Aplodontoidea. Field Mus. Nat. Hist., Geol. Ser., v. 9, pp. 1-30.

McKenna, M. C., 1966: Synopsis of Whitneyan and Arikareean camelid phylogeny. Amer. Mus. Nov., no. 2253, pp. 1-11.

Merriam, J. C., 1911: Tertiary mammal beds of Virgin Valley and Thousand Creek in Northwestern Nevada. Univ. Calif. Publ. Geol. Sci., v. 6, pp. 199-304.

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Miall, A. D., 1977: A review of the braided river depositional environment. Earth Sci. Rev., v. 13, pp. 1-62.

_____________, 1978: Lithofacies types and vertical profile models in braided river deposits: A summary. In Miall, A. D., ed., Fluvial sedimentology, Can. Soc. Pet., Geol. Mem. 5, pp. 597-604.

Monroe, J. S., 1976: Vertebrate paleontology, stratigraphy, and sedimentation of the Upper Ruby River basin, Madison County, Montana. Ph.D. dissertation, University of Montana, Missoula, Montana, 301 p.

_____________, 1981: Late Oligocene-Early Miocene facies and lacustrine sedimentation, Upper Ruby River basin, southwestern Montana. Jour. Sed. Pet., v. 51, no. 3, pp. 939-951.

Nelson, W. L., 1962: A seismic study of the North Boulder Valley and other selected areas, Jefferson and Madison Counties, Montana. M.S. thesis, Indiana University, Bloomington, Indiana, 33 p.

Nilson, T. H., 1982: Alluvial fan deposits. In Scholle, P. A., and Spearing, D. R., eds., Sandstone depositional environments. Amer. Assoc. Pet. Geol., Memoir 31, pp. 49-86.

Osborn, H. F., 1918: Equidae of the Oligocene, Miocene, and Pliocene of North America, iconographic type revison. Mem. Am. Mus. Nat. Hist., v. 2, 217 p.

_____________, 1929: The Titanotheres of ancient Wyoming, Dakota, and Nebraska. U. S. Printing Office, Wash., Monograph 55, 2 vols., 953 p.

Pardee, J. T., 1950: Late Cenozoic block faulting in western Montana. Geol. Soc. Amer. Bull., v. 61, pp. 356-406.

Parker, J. S., 1961: A preliminary seismic investigation of Tertiary basin fill in the Jefferson Island Quadrangle, Montana. M.A. thesis, Indiana University, Bloomington, Indian, 35 p.

Peterson, O. A., 1909: A revision of the entelodonts. Carn. Mus. Mem., v. 4, pp. 41-158.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

__________________, 1920: The American Diceratheres. Carn. Mus. Mem., v. 7, no. 6, pp. 414-477.

Petkewich, R. M., 1972: Tertiary geology and paleontology of the northeastern Beaverhead and lower Ruby River basins, southwestern Montana. Ph.D. dissertation, University of Montana, Missoula, Montana, 365 p.

Picard, M. D., and High, L. R., Jr., 1972: Paleoenvironmental reconstruction in an area of rapid facies changes, Parachute Creek Member of Green River Formation (Eocene), Uinta Basin, Utah. Geol. Soc. Amer. Bull., v. 83, pp. 2689-2708.

____, 1973: Sedimentary structures of ephemeral streams. Elsevier Scientific Publ. Co., Amsterdam, London, New York, 223 p.

Proffett, J. M., Jr., 1977: Cenozoic geology of the Yerington district, Nevada, and implications for the nature and origin of Basin and Range faulting. Geol. Soc. Amer. Bull., v. 88, pp. 247-266.

Rasmussen, D. L., 1973: Extension of the middle Tertiary unconformity into western Montana. Northwest Geology, v. 2., pp. 27-35.

Reineck, H. E., and Singh, I. B., 1980: Depositional sedimentary environments, with reference to terrigenous clastics. Springer-Verlag Publ., Berlin, Heidelberg, New York, 2nd ed., 549 p.

Reynolds, M. W., 1979: Character and extent of basin-range faulting, western Montana and east-central Idaho, In Newman, G. W., and Goode, H. D., eds., Basin and Range Symposium, Rocky Mt. Assoc. Geol., and Utah Geol. Assoc., pp. 185-193.

Richard, B. H., 1966: Geologic history of the intermontane basins of the Jefferson Island Quadrangle, Montana. Ph.D. dissertation, Indiana University, Bloomington, Indiana, 73 p.

Robinson, G. D., 1960: Middle Tertiary unconformity in southwestern Montana. U. S. Geol. Survey Prof. Paper 400-B, pp. B227-B228.

__________________, 1963: Geology of the Three Forks Quadrangle, Montana. U. S. Geol. Survey Prof. Paper 370, 143 p.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

________________, 1967: Geologic map of the Toston Quadrangle, southwestern Montana. U. S. Geol. Survey Misc. Geol. Inv. Map I-486.

Runkel, A. C., in preparation: Tertiary geology of the Smith River basin, Meagher County, Montana. M.S. thesis, University of Montana, Missoula, Montana.

Rust, B. R., and Koster, E. H., 1984: Coarse alluvial deposits. In Walker, R. G., ed., Facies Models, 2nd edition, Geoscience Canada, Reprint series I, Geol. Soc. Canada, pp. 53-69.

Savage, D. E., and Russell, D. E., 1983: Mammalian Paleofaunas of the World. Reading, Massachusetts: Addison-Wesley Pub. Co., 432 p.

Schmidt, C. J., and O'Neill, J. M., 1982: Structural evolution of the southwest Montana transverse zone, In Powers, W., ed., The western overthrust belt from Alaska to Mexico, Rocky Mt. Assoc. Geol., p. 193-218.

Schultz, C. B., and Falkenbach, C. H., 1940: Merycochoerinae, a new subfamily of oreodonts. Bull. Am. Mus. Nat. Hist., v. 77, pp. 213-306.

____________________________________, 1950: Phenacocoelinae, a new subfamily of oreodonts. Bull. Am. Mus. Nat. Hist., v. 95, art. 3, pp. 87-150.

____________________________________, 1954: Desmatochoerinae, a new subfamily of oreodonts. Bull. Am. Mus. Nat. Hist., v. 105, art. 2, pp. 143-256.

____________________________________, 1968: The phylogeny of the oreodonts, parts 1 and 2. Bull. Amer. Mus. Nat. Hist., v. 139, pp. 1-498.

Scott, W. B., 1941: The mammalian fauna of the White River Oligocene, pt. 5, Perissodactyla. Trans. Amer. Phil. Soc., N.S., v. 28, pp. 747-980.

Shotwell, J. A., 1958: Evolution and biogeography of the Aplodontid and Mylagaulid rodents. Evol., v. 12, no. 4, pp. 451-484.

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Stewart, J. H., 1980: Regional tilt patterns of late Cenozoic basin-range fault blocks, western United States. Geol. Soc. Amer. Bull., v. 91, no. 8, pp. 460-464.

Streeter, M. E., 1983: The geology of the southern Bull Mountain area, Jefferson County, Montana. M.S. thesis, Western Michigan University, Kalamazoo, Michigan, 88 p.

Tedford, et al., (in press): Faunal succcession and biochronology of the Arikareean through Hemphillian interval (Late Oligocene through Earliest Pliocene Epochs), North America.

Thompson, G. R., Fields, R. W., and Alt, D., 1981: Tertiary paleoclimates, sedimentation patterns and uranium distribution in southwestern Montana, In Tucker, T. E., ed., Montana Geol. Soc. Field Conf. Sym. Guidebook Southwest Montana, pp. 105-109.

______________________________, 1982: Land-based evidence for Tertiary climate variations, Northern Rockies. Geology, v. 10, pp. 413-417, August.

Troxell, E. L., 1921: A study of Diceratherium and the Diceratheres. Am. Jour. Sci., v. 2., pp. 197-208.

Vanderhoof, V. L., and Gregory, J. T., 1940: A review of the genus Aelurodon. Univ. Calif. Publ. Geol. Sci., v. 25, pp. 143-164.

Vessell, R. K., and Davies, D. K., 1981: Nonmarine sedimentation in an active fore arc basin. In Ethridge, F. G., and Flores, R. M., eds., Recent and Ancient Nonmarine Depositional Environments: Models for Exploration. Soc. Econ. Paleo. Min. Spec. Publ. 31, pp. 31-45.

Visher, G. S., 1972: Physical characteristics of fluvial deposits. In Rigby, J. K., and Hamblin, W. K., eds., Recognition of Ancient Sedimentary Environments, S.E.P.M. Spec. Publ., 16, pp. 84-97.

Walker, R. G., and Cant, D. J., 1984: Sandy fluvial systems. In Walker, R. G., ed., Facies Models, 2nd edition, Geoscience Canada, Reprint series I, Geol. Soc. Canada, pp. 71-89.

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Wilson, D., 1962: A seismic and gravity investigation of North Boulder River and Jefferson River valleys, Madison and Jefferson counties, Montana. M.A. thesis, Indiana University, Bloomington, Indiana, 43 p.

Wilson, J. A., 1957: Early Miocene entelodonts, Texas coastal plain. Am. Jour. Sci., v. 255, pp. 641-649.

Wood, H. E., 1933: A fossil rhinoceros (Diceratherium armatum, Marsh) from Gallatin county, Montana. Proc. U. S. Nat. Mus., v. 82, art. 7, 4 p.

Wood, H. E., et al., 1941: Nomenclature and correlation of the North American continental Tertiary. Geol. Soc. Amer. Bull., v. 52, pp. 1-48.

Woodward, L. A., 1981: Tectonic framework of disturbed belt of west-central Montana. Amer. Assoc. Pet. Geol. Bull., v. 65, no. 2, pp. 291-302.

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APPENDIX I

DESCRIPTION OF FOSSIL MATERIAL

The fossil material is listed by fauna in order of decreasing age. Tortoise carapace fragments are common in every local fauna. These are not listed or described because they are too fragmentary for generic determination.

Vertebrate taxa from previous collecting by field parties of the Carnegie Museum of Pittsburgh and the American Museum of Natural History in the North Boulder River basin is incorporated into the local faunas listed. Assignment of Montana vertebrate locality numbers to this material was accomplished by locality descriptions provided by the museums, and in the case of the American Museum of Natural History old photos were also used.

Descriptions of vertebrate taxa contained in the collections in the Carnegie Museum and the American Museum of Natural History (including the Frick Collection) are from lists provided by the museums. Some specimens collected in the early 1900's are still not fully prepared, while other taxa listed lack museum numbers but are known to have been collected at certain localities (R. Tedford, pers. comm., 1984). Some of the descriptions of vertebrate taxa from these collections listed in this Appendix are fragmentary for these reasons.

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The taxonomy of oreodonts in the University of Montana Museum of Paleontology collection follows Lander (1977). Other oreodont material used in local faunas is from lists provided by the Carnegie Museum and the American Museum of Natural History. This material is not described and is referred to by the taxonomic names used by the museums, although Lander's (1977) revised classification is also noted.

Symbols and abbreviations used in this section are as follows:

AMNH :	American Museum of Natural History, New York; specimen number
a-p :	antero-posterior
BEG :	Bureau of Economic Geology, University of Texas, Austin; specimen number
cf. :	compares with
CIT :	California Institute of Technology, Pasadena; specimen number
CM :	Carnegie Museum, Pittsburgh; specimen number
FAMNH:	Frick Collection, American Museum of Natural History, New York; specimen number
MV :	University of Montana Vertebrate Locality
NM :	Nebraska Museum, Lincoln; specimen number
PM :	Princeton Museum, Princeton; specimen number
SDSM :	South Dakota School of Mines Museum, Rapid City; specimen number

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tr : transverse

UM : University of Montana Museum of Paleontology, Missoula; specimen number

USNM : United States National Museum, Washington, D.C.; specimen number

YPM : Yale Peabody Museum, New Haven; specimen number

All measurements listed are given in millimeters.

All vertebrate fossil specimens are housed in the University of Montana Museum of Paleontology except where noted. Twenty-nine University of Montana (MV) localities were named in this report and are listed below. Localities previously sampled by field parties of the American Museum of Natural History (AMNH and/or FAMNH) or Carnegie Museum of Pittsburgh (CM) are indicated.

University of Montana Vertebrate Localities
(See Plate I for locations)

Number	Locality Name	Other Museum Collections
MV8405	Doherty Mountain North #1	
MV8405	Doherty Mountain North #2	(CM)
MV8406	Doherty Mountain North #3	
MV8407	Doherty Mountain North #4	
MV8408	Doherty Mountain North #5	
MV8409	Negro Hollow Scarp	

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MV8410	Negro Hollow Turret	
MV8411	Negro Hollow Conglomerate Cap	
MV8412	Prussack-Klein Ranch #1	
MV8413	Prussack-Klein Ranch #2 East	
MV8414	Prussack-Klein Ranch #3 North	(AMNH)(FAMNH)
MV8415	Dawson Ranch	
MV8416	Wilson Park Road #1	
MV8417	McKanna Spring Knob	
MV8418	Wilson Park Road #2	
MV8419	Wilson Park Road #3	
MV8420	Wilson Park Road #4	
MV8421	Carey Ranch #1	
MV8422	Carey Ranch #2	
MV8423	Cottonwood Creek	(AMNH)
MV8424	South Fork Cottonwood Creek	
MV8425	Brenner (Foran) Ranch	
MV8426	Monforton Ranch North	
MV8427	Monforton Ranch West	
MV8428	Conrow Creek North	
MV8429	Conrow Creek South	
MV8430	Red Hill	(CM)
MV5907	Negro Hollow	(AMNH)(FAMNH)
MV6003	McKanna Spring	(AMNH)(FAMNH)

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Monforton Ranch Local Fauna

Class MAMMALIA Linnaeus, 1758
Order PRIMATES Linnaeus, 1758
Family OMOMYIDAE Gazin, 1958
Genus *Macrotarius* Clark, 1941
Macrotarius montanus

LOCALITY AND REFERRED SPECIMEN: MV8405-CM9592, partial right ramus.

DISCUSSION: See Clark (1941) for complete description.

Order PERISSODACTYLA Owen, 1848
Family BRONTOTHERIIDAE Marsh, 1887
Genus *Teleodus* Marsh, 1890
Teleodus cf. *primitivus* Lambe, 1908

LOCALITY AND REFERRED SPECIMEN: MV8407-UM8447, partial left and right premaxillary with alveoli of left I^1-I^3, C, P^2 and right I^1-I^3.

DESCRIPTION: I^2 alveolus larger than I^1 or I^3; I^1 and I^3 subequal in size; I^3 slightly larger and deeper rooted than I^1; size of canine alveolus indicates very large tooth; P^2 double rooted, of equal depth and size.

DISCUSSION: Loss of incisors is a distinctive characteristic when differentiating Eocene from Oligocene titanotheres (Osborn, 1929). The only known Oligocene form to retain all three incisors is *Teleodus* (Osborn, 1929). Therefore, UM8447 is assigned to *Teleodus*, although *Protitanotherium* known from the upper Eocene

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is similar in size and dental morphology. Also, the size of the alveoli of UM8447 suggests that I^3 is larger than I^1, which is a characteristic found in the lower jaw of *T. primitivus*, unlike *T. avus* and *Protitanotherium* (Osborn, 1929).

brontothere
gen. and sp. indet.

LOCALITIES AND REFERRED SPECIMENS: MV8427-UM8860, partial left ramus with alveoli of M_3 except for anterior portion of first root; UM8866, fragment of proximal end of humerus; UM8863, partial right trapezoid; UM8864, left scaphoid; UM8865, right lunar; UM8861, unidentified bone fragments; MV8430-UM8877, tooth fragments.

DISCUSSION: The referred material is too fragmentary for more than family identification. It is important to note that the alveoli of UM8860 measures (a-p) greater than 77 mm. This size range is found within Late Eocene and Oligocene types reported by Osborn (1929).

Family RHINOCEROTIDAE Owen, 1845
rhinocerotid
gen. and sp. indet.

LOCALITY AND REFERRED SPECIMEN: MV8427-UM8862, molar fragments.

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Order ARTIODACTYLA Owen, 1848
Family ANTHRACOTHERIDAE Leidy, 1869
Genus *Aepinacodon* Troxell, 1921
Aepinacodon sp.

LOCALITY AND REFERRED SPECIMEN: MV8405-UM8442, right M^1.

DISCUSSION: The material is a single heavily worn tooth collected from sediments previously dated as Chadronian. Of the two Chadronian genera, *Aepinacodon* can be separated from *Heptacodon* by the invasion of the mesostyle by the transverse valley in the former (Macdonald, 1956). UM8442 has this characteristic. *Elomeryx* is similar in size and molar pattern to *Aepinacodon* but it is not known before the Whitneyan (Macdonald, 1956).

Family MERYCOIDODONTIDAE Hay, 1902
Genus cf. *Oreonetes* Douglass, 1901
cf. *Oreonetes anceps* Douglass, 1901

LOCALITY AND REFERRED SPECIMEN: MV8409-UM8455; left M^2.

DISCUSSION: This specimen compares in size and dental morphology with *Oreonetes anceps* specimens from McCarty's Mountain, Montana. *Limnenetes platyceps* is similar in size to *O. anceps*, but UM8455 is clearly more aligned to the latter (see below).

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Measurements of cf. *Oreonetes anceps*

		UM8455	UM0928[a]	UM0937[b]
M^2	a-p	11.2	10.6	10.2
	tr	11.8	11.8	9.7

[a] *Oreonetes anceps*, from MV5813--McCarty's Mountain Locality 1, Madison County, Montana.

[b] *Limnenetes platyceps*, from MV5813--McCarty's Mountain Locality 1, Madison County, Montana.

Genus cf. *Oreonetes* Douglass, 1901
cf. *Oreonetes*

LOCALITY AND REFERRED SPECIMEN: MV8427-UM8876, left dP_4-M_2.

DISCUSSION: Tentatively assigned to this genus because of size and the presence of *Oreonetes* from similar aged sediments in the North Boulder River basin.

Merycoidon culbertsoni
(*Prodesmatochoerus natronensis*; Lander, 1977)

LOCALITIES AND REFERRED SPECIMENS: MV 8430-CM9177, partial skull, jaws, and skeletal fragments.

DISCUSSION: See Lander (p. 106, 1977) for diagnosis.

Merycoidon gracilis
(*Oreonetes*, new species; Lander, 1977)

LOCALITIES AND REFERRED SPECIMENS: MV8430-CM9342, partial skull and jaw fragments.

DISCUSSION: See Lander (p. 117, 1977) for diagnosis.

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Family CAMELIDAE Gray, 1821
camelid
gen. and sp. indet.

LOCALITY AND REFERRED SPECIMEN: MV8407-UM8446, left M^3.

MEASUREMENTS: a-p 22.7; tr 15.2.

Negro Hollow Local Fauna

Class MAMMALIA Linnaeus, 1758
Order LAGOMORPHA Brandt, 1855
lagomorph
gen. and sp. indet.

LOCALITY AND REFERRED SPECIMEN: MV8425-UM8859, incisor.

Order RODENTIA Bowdich, 1821
Family APLODONTIDAE Trouessart, 1897
Genus *Allomys* Marsh, 1877
Allomys sp.

LOCALITY AND REFERRED SPECIMEN: MV8425-UM8849, right P^4.

DESCRIPTION: Tooth heavily worn; protoconule, metaconule and protocone with more wear than buccal cusps; buccal cusps prominent on developed w-shaped ectoloph; protoloph and metaloph not well developed; protoloph not connected with anterior cingulum or metaloph; ectoloph with prominent anterior extension of parastylar lobe.

COMPARISON: The preceding description agrees with the generic characteristics listed by McGrew (1941) for *Allomys*. More complete material would be required for a valid species distinction.

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rodent
gen. and sp. indet.

LOCALITY AND REFERRED SPECIMENS: MV8425-UM8858, incisor; UM8857, partial incisor.

Order MARSUPIALIA Illiger, 1811
Famliy DIDELPHIDAE Gray, 1821
Genus *Peratherium* Hough, 1961
Peratherium sp.

LOCALITY AND REFERRED SPECIMENS: MV8425-UM8846, right upper molar; UM8847, partial lower cheek tooth.

DISCUSSION: Material too incomplete for species distinction but clearly aligned with *Peratherium*.

Order CARNIVORA Bowdich, 1821
Family CANIDAE Gray, 1821
Genus *Nothocyon* Matthew, 1899
cf. *Nothocyon geismarianus*

LOCALITY AND REFERRED SPECIMEN: UM8425-UM8850, partial right ramus with P_3-P_4 and alveoli of M_2-M_3.

DESCRIPTION: P_3-P_4 crowded. P_3 with small anterior and posterior accessory cusps; protoconid sharp; metaconid small; P_4 with well developed anterior and posterior accessory cusp; protoconid sharp; metaconid well-developed.

COMPARISON: UM8850 is similar in size to *N. geismarianus* (see below), although it cannot be separated from *Hesperocyon gregorii* without a comparison of M_1 or P^4 (Macdonald, 1963).

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Measurements of cf. *Nothocyon geismarianus*

	UM8850	AMNH6685[a]	AMNH12872[a]
P^3, a-p	6.0	6.5	6.2
tr	2.5	2.5	2.2
P^4, a-p	6.5	6.4	6.7
tr	2.9	3.0	2.8

[a] from Macdonald (1963)
6885 type, from John Day Formation, Oregon.
12872, from Monroe Creek Formation, Nebraska.

Genus *Nothocyon* Matthew, 1899
cf. *Nothocyon*

LOCALITY AND REFERRED SPECIMENS: MV8425-UM8851, left M^1; UM8852, right M^1; UM8848, right P^2.

DISCUSSION: These isolated teeth are the correct size and have the physical characteristics for assignment to *Nothocyon*. Also, this material was found in the same screening sample as UM8850. Therefore, these teeth are tentatively assigned as cf. *Nothocyon*, but *Hesperocyon* cannot be entirely eliminated as a possibility.

Order PERISSODACTYLA Owen, 1848
Family RHINOCEROTIDAE Owen, 1845
Genus *Diceratherium* Marsh, 1875
Diceratherium cf. *armatum* Marsh, 1875

LOCALITY AND REFERRED SPECIMENS: MV5907-UM8470, left maxillary with P^1-P^4.

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DESCRIPTION: P^1 medifossette well isolated; cingula well developed on the anterior portion of the protoloph. Anterior, lingual, and posterior cingula of P^2 well developed and continuous; protocone and hypocone subequal in size. Cingula in P^3-P^4 similar to P^2; hypocone and protocone connected by mures; metalophs thin due to anterior-posterior compression of hypocone; this condition more pronounced in P^4 than P^3.

COMPARISON: UM8470 is similar to *D. armatum* except it is significantly smaller. *D. armatum* is the only described species of the genus that has mures and well-developed, continuous cingula in P^2-P^4. Described premolars of *D. gregorii* are somewhat larger in size but lack continuous cingula and have weak mures if present (Peterson, 1920; Green, 1958). The holotype of *D. niobarense* is close in size and has similar cingula but lacks mures (Peterson, 1920).

The inability to classify harmoniously the diceratheres has existed for some time (Troxell, 1921). The difficulty in assigning UM8470 to any specific species within this group is probably a reflection of the great variability of the genus during the Late Arikareean. The decision to weigh one character above another is a dilemma that exists within the diceratheres. The author tentatively follows the scheme that size

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is subordinate to other features when dealing with this problem. A size comparison between UM8470 and previously described material is shown below to demonstrate the significant difference in widths of the premolars.

Measurements of *Diceratherium* cf. *armatum*

		UM8470	USNM 11682[a]	YPM 100003[b]	SDSM 53584[c]
P^1,	a-p	23.3	26.5	29	27.5
	tr	19.4	23.1	24	25.5
P^2,	a-p	28.9	31.5	31	31.8
	tr	32.6	42.7	40	38.6
P^3,	a-p	34.2	36.1	35	34.6
	tr	38.7	50.5	45	49.3
P^4,	a-p	36.0	36.5	38	37.9
	tr	43.6	53.5	49	53.8

[a] *Diceratherium armatum*, from Gallatin County, Montana (Wood, 1933).

[b] Holotype *D. armatum*, from John Day Formation, Oregon (Peterson, 1920).

[c] *D. armatum*, from Lower Rosebud Formation, South Dakota (Green, 1958).

rhinocerotid
gen. and sp. indet.

LOCALITY AND REFERRED SPECIMENS: MV8423-UM8823, left astragulus; UM8824, tooth fragments; MV8424-UM8833, tooth fragments.

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Family EQUIDAE Gray, 1821
equid
gen. and sp. indet.

LOCALITIES AND REFERRED SPECIMENS: MV8423-UM8845, right calcaneum; MV8423-UM8828, distal phalanx; UM8829, medial phalanx; UM8830, molar fragment.

Order ARTIODACTYLA Owen, 1848
Family ENTELODONTIDAE Lydekkler, 1883
Genus *Dinohyus* Peterson, 1907
Dinohyus hollandi

LOCALITY AND REFERRED SPECIMEN: MV8426-UM8875, a nearly complete skull with articulated mandible. The skull is missing the nasals and a large portion of both left and right frontals and lacrymals. The posterior portion of the left ramus is also missing. All teeth are present except for left I^1-I^2, I_1-I_2, and right I^1.

DISCUSSION: UM8875 represents an entelodont of great size. The skull is approximately 90 cm in length, which is similar in size to Early Miocene forms. UM8875 compares very closely to the type of *D. hollandi* described by Peterson (1909) except for two notable differences. The mandible of UM8875 has a well-developed anterior knob-like process similar to those found in some species of *Archeotherium*. Also, M^3 of UM8875 has a distinct metaconule which is weakly delineated in the type. Unfortunately, UM8875 is not fully prepared.

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Whether other differences will arise when preparation is complete is a matter of speculation.

Size differences between the anterior mandibular processes of UM8875 and previously described specimens may be related to sexual dimorphism. Scott (1941) suggested that differences in these processes in some species of Archeotherium were related to sex. This may explain the size variation exhibited by UM8875 and the type specimen.

A comparison of dental measurements of the North Boulder material with known specimens of D. hollandi clearly illustrates that UM8875 falls within the normal range of variation expected within the species (see below). Therefore, the differences listed above are not at the present considered significant enough to preclude the material from assignment to D. hollandi.

Measurements of Dinohyus hollandi

	UM8875	CM1594[a]	NM20708[b]	BEG40223-1[b]
Length, M^1-M^3	151.0	132	---	---
Canine, a-p	50.8	50	---	---
P^1, a-p	38.0	39	---	---
P^2, a-p	39.0	38	---	---
P^3, a-p	42.5	42	---	---

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Measurements of <u>Dinohyus</u> <u>hollandi</u> (continued)

	UM8875	CM1594[a]	NM20708[b]	BEG40223-1[b]
P^4, a-p	38.7	37	38	41.0
M^1, a-p	46.2	42	43	45.8
M^2, a-p	54.8	45	---	---
M^3, a-p	54.5	45	---	---
tr	54.1	47	---	---
Length, M_1-M_3	155.0	137	139	162
I_2, a-p	22.1	25	---	---
I_3, a-p	30.4	34	---	---
Canine, a-p	50.7	48	---	---
P_2, a-p	40.8	40	---	---
P_3, a-p	51.0	54	55	60.1
P_4, a-p	45.0	45	46	55.0
M_1, a-p	43.2	42	42	50.7
M_2, a-p	50.2	47	49	55.0
M_3, a-p	56.0	50	55	55.2
tr	41.0	39	40	44.8
Depth of mandible at P_2	109	100	111	118
Depth of mandible at M_3	123	120	114	117

[a] Type specimen from Agate Springs Quarry, Nebraska (Peterson, 1909).

[b] NM20708 from Agate Springs Quarry, Nebraska (Wilson, 1957).
BEG40223-1 from San Jacinto County, Texas (Wilson, 1957).

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Family MERYCOIDODONTIDAE Thorpe, 1923
Genus *Hypsiops* Douglass, 1907
Hypsiops breviceps

LOCALITY AND REFERRED SPECIMEN: MV8423-UM8818, anterior palatal portion of skull with left C-M^2, and right C-P^3.

DISCUSSION: This specimen compares well in dental morphology to *H. bannackensis* (UM3546) identified by Bruce Lander (Monroe, 1976). According to Lander the genus *Hypsiops* is characterized by: P^1 and P^2 with prominent anterior intermediate crest, usually oriented diagonally but directed toward main cone; anterior lateral corner of P^1 and P^2 rounded; P^3 almost square (Monroe, 1976). UM8818 possesses these features.

H. breviceps can be distinguished from *H. bannackensis* by its smaller size (Lander, 1977). UM8818 is considerably smaller than *H. bannackensis* (UM3546) (see below). Also, UM8818 compares closely in size to specimens referred to *H. brachymelis*. The type of this species was described from deposits in the North Boulder River basin similar in age to those of UM8818 (Schultz and Falkenbach, 1950). In his revision of the oreodonts Lander (1977) has synonymized *H. brachymelis* with *H. breviceps*.

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Measurements of *Hypsiops breviceps*

	UM8818	UM3546[a]	F:AMNH33313[b]
Length P^1-P^4	43.5	52.3	43.5

[a] *H. bannackensis*, from MV7244, upper Ruby River basin, Madison County, Montana (Monroe, 1976).

[b] *H. brachymelis petersoni*, from Niobrara County, Wyoming (Schultz and Falkenbach, 1950).

Merycoides longiceps

LOCALITIES AND REFERRED SPECIMENS: MV8423-UM8819, anterior portion of skull with left C-P^1, P^3-M^2, and right C-P^2, M^1-M^2; portion of jaw with left P^1-M^2, and right P^1-P^2, P^4-M^2; MV5907-UM8472, anterior portions of mandible with left I_1-P_3, and right I_1-M_1; UM8471, crushed posterior portion of skull.

DISCUSSION: UM8819 compares very closely in size to *Pseudodesmatochoerus longiceps*, whose type was described from similar aged deposits in the North Boulder River basin (see below) (Schultz and Falkenbach, 1954). Lander (1977) synonymized *P. longiceps* with *M. longiceps*.

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Measurements of *Merycoides longiceps*

	UM8819	UM8472	AMNH9732[a]
Length P^1-P^4	46.1	---	47
Length P_1-P_4	48.1	47.6	49

[a] *P. longiceps* from MV5907, North Boulder River basin, Jefferson County, Montana (Schultz and Falkenbach, 1954).

Pseudodesmatochoerus longiceps
(*Merycoides longiceps*, Lander, 1977)

LOCALITY AND REFERRED SPECIMENS: MV5907-FAMNH44953, partial skull and partial left ramus; FAMNH34474, mandible with I_1-M_3; AMNH9732, skull with I^1-M^3, mandible with I_2-M_3, assorted skeletal elements.

DISCUSSION: Part of AMNH collection, not present in University of Montana Museum of Paleontology collection.

Hypsiops brachymelis
(*Hypsiops breviceps*, Lander, 1977)

LOCALITY AND REFERRED SPECIMENS: MV5907-AMNH9731, skull with I^1-M^3, mandible with I_1-M_3, assorted skeletal elements.

DISCUSSION: Part of AMNH collection only.

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Pseudomesoreodon rolli
(*Hypsiops bannackensis*, Lander, 1977)

LOCALITY AND REFERRED SPECIMEN: MV5907-FAMNH34481, partial skull with P^2-M^3.

DISCUSSION: Part of AMNH collection only.

Pseudomesoreodon boulderensis
(*Hypsiops bannackensis*, Lander, 1977)

LOCALITY AND REFERRED SPECIMEN: MV5907-FAMNH44883, partial skull with I^1-M^3, mandible with C-M_3.

DISCUSSION: Part of AMNH collection only.

merycoidodontid
gen. and sp. indet.

LOCALITIES AND REFERRED SPECIMENS: MV8423-UM8838, broken right astragulus; UM8839, tooth fragments; MV8423-UM8831, partial molar tooth.

Family CAMELIDAE Gray, 1821
Genus *Oxydactylus* Peterson, 1904
Oxydactylus lacota

LOCALITY AND REFERRED SPECIMEN: MV5907-AMNH9742-3.

DISCUSSION: Material of unknown composition, part of AMNH collection only.

Oxydactylus cf. *lacota*

LOCALITY AND REFERRED SPECIMENS: MV8423-no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

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Stenomylus cf. *hitchcocki*

LOCALITY AND REFERRED SPECIMENS: MV5907-FAMNH62362, 62361, 62363.

DISCUSSION: Material of unknown composition, part of AMNH collection only.

camelid
gen. and sp. indet.

LOCALITIES AND REFERRED SPECIMENS: MV5907-UM8475, jaw fragment with alveoli of C and P_2; UM8476, lower right M_1; MV8423-UM8827, proximal phalanx.

Family HYPERTRAGULIDAE Cope, 1879
Genus *Nanotragulus* Lull, 1922
Nanotragulus sp.

LOCALITY AND REFERRED SPECIMEN: MV5907-no number.

DISCUSSION: Material of unknown composition,part of AMNH collection, museum number not available.

McKanna Spring Local Fauna

Class MAMMALIA Linnaeus, 1758
Order RODENTIA Bowdich, 1821
Family MYLAGAULIDAE
Genus *Mylagaulus*
Mylagaulus sp.

LOCALITY AND REFERRED SPECIMEN: MV6003-UM8525, P^4.

DISCUSSION: This tooth contains five lakes; therefore, according to Shotwell (1958), it is referable to a Barstovian species of *Mylagaulus*.

MEASUREMENTS: a-p, 4.1; tr, 5.7.

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Order CARNIVORA Bowdich, 1821
Family CANIDAE Gray, 1821
Genus *Aelurodon* Leidy, 1858
Aelurodon cf. *saevus* Leidy, 1858

LOCALITY AND REFERRED SPECIMEN: MV8418-UM8590, partial left mandible with P_2-P_4.

DESCRIPTION: P_2-P_4 expanded posteriorly, forming shallow lingually-situated basin; P_2-P_4 double-rooted, with stepped posterior borders; P_2-P_4 large, robust, with small anterior and posterior cuspules; protoconids form sharp summits with small metaconids on posteriorly sloping median crests.

DISCUSSION: UM8590 is similar in physical characteristics to *Aelurodon*. It is tentatively referred to *A. saevus* because of the slightly spaced premolars, which apparently separates it from *A. taxoides* (Vanderhoof and Gregory, 1940). Also, the size of individual teeth is similar to the type of *A. saevus* (see below).

Measurements of *Aelurodon* cf. *saevus*

	UM8590	AMNH8305[a]
P_1, a-p	9.6	9.1
tr	6.4	5.1
P_2, a-p	11.3	11.5
tr	7.6	6.5
P_3, a-p	14.5	16.1
tr	9.7	9.4

[a] *A. saevus* from Tonopah, Nevada (Henshaw, 1942).

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Family MUSTELIDAE Swainson, 1835
Genus *Leptarctus*
Leptarctus cf. *bozemanensis*

LOCALITY AND REFERRED SPECIMEN: MV6003--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

Order PERISSODACTYLA Owen, 1848
Family EQUIDAE Gray, 1821
Genus *Merychippus* Leidy 1857
Merychippus *seversus* Cope, 1878

LOCALITIES AND REFERRED SPECIMENS: MV8415-UM8548, left ramus with P_3-M_3; UM8549, left ramus with M_1-M_3; MV8418-UM8592, left M^2; MV8419-UM8596, left P^4; UM 8599, right P^4; MV6003-UM0533, left M^3.

DISCUSSION: This species is commonly found in Miocene strata in Montana. Since this species has been described many times by previous workers in intermontane basins (see Kuenzi, 1966, or Monroe, 1976), any further description seems unnecessary.

The material found in the North Boulder conforms closely to Osborn's (1918) description of the type:

1. Molars moderately hypsodont, curved;
2. Protocone an elongate oval with anterior spur directed toward proconule;
3. Hypocone elongate oval in section, distinct from metaconule;
4. Protoconule and metaconule separated by fossettes;

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5. Borders of metaconule crescent ptychoid, protoconule crochet junction with plicaballin;
6. Ectoloph without median paracone and metacone.

DISCUSSION: Difficulties arise when separating *Merychippus seversus* from *M. isonesus* because of their very similar descriptions in Osborn's (1918) revision of the Equidae. Both species were described from the Mascall Formation of Oregon by Cope in the late 1800's (Osborn, 1918). Downs (1956), when reviewing the Mascall Fauna, concluded that *M. isonesus* was synonymous with *M. seversus* and therefore *M. seversus* should take precedence due to its earlier description. I follow this system, and all material in question is referred to *M. seversus*.

Merychippus cf. *seversus* Cope, 1878

LOCALITIES AND REFERRED SPECIMENS: MV8414-UM8506, right cheek tooth; MV603-UM8515, two left cheek teeth; UM8516, left M_3; UM8517, deciduous left cheek teeth; UM8518, left P^2; UM0891, left P^4, partial left M^1; UM5125, three molars; MV8417-UM8584, right cheek tooth; MV8422-UM8814, right P^3-M^2.

DESCRIPTION: Fragmentary or poorly preserved material that is referred to this species by size and cusp pattern.

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Merychippus cf. *isonesus* Cope, 1889

LOCALITIES AND REFERRED SPECIMENS: MV6003-FAMNH60954, unknown material; MV8414--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available for material from MV8414.

Merychippus cf. *intermontanus*

LOCALITY AND REFERRED SPECIMEN: MV6003--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

cf. *Merychippus* sp. Leidy, 1857

LOCALITY AND REFERRED SPECIMENS: MV8414-UM8508, right astragulus; MV6003-UM8519, tooth fragments; UM8531, distal end of tibia, UM8530, left calcaneum; UM8521, right navicular, astragulus, cuboid; left ectocuneiform; phalanx; UM0529, distal end of cannon bone; UM0893, left astragulus; UM5123, tooth fragments; UM5130, tooth fragments; UM5118, isolated upper molar; UM0530, fragment of upper molar; UM0693, fragment of upper molar; MV8417-UM8562, tooth fragments; UM8577, four medial phalanges; MV8418-UM8591, right ectocuneiform; MV8419-UM8597, tooth fragments; UM8800, tooth fragments; MV8420-UM8802, jaw symphysis; UM8808, tooth fragment;

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MV8422-UM8813, medial phalanx; MV8412-UM8481, tooth fragments; MV8411-UM8468, tooth fragments.

DISCUSSION: All of the above-listed material is definitely equid and the right size for reference to Merychippus. In addition, it was collected from sediments known to be Barstovian in age.

Order ARTIODACTYLA Owen, 1848
Family MERYCOIDODONTIDAE Hay, 1902
Genus Brachycrus Douglass, 1900
Brachycrus laticeps

LOCALITY AND REFERRED SPECIMENS: MV8416-UM8554, partial superior dentition including 3 incisors, right C-P^4, M^3, left C-P^4, M^2-M^3, tooth fragments; UM8557, proximal end of left and right ulna, proximal end of right radius; UM8556, left lunar; UM8553, left cuboid, navicular, and ectocuneiform; UM8555, right lunar, cuboid, scaphoid, trapezoid, unciform, and magnum; UM8558, metacarpals II-V, two proximal phalanges.

DISCUSSION: The material is from a large oreodon from sediments of known Barstovian age. All skeletal elements were recovered from one site, which, along with their uniform size, suggests that they all belong to one individual.

UM8554 is most similar to Brachycrus altiramus from the Miocene deposits of the Lower Madison Valley, Montana (see below) (Schultz and Falkenbach, 1940).

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This taxa is now considered synonymous with Brachycrus laticeps (Lander, 1977).

Measurements of Brachycrus laticeps

	UM8554	AMNH9746[a]
Width of M^3	33.7	33

[a] B. altiramus from Lower Madison Valley, Gallatin County, Montana (Schultz and Falkenbach, 1940).

Family CAMELIDAE Gray, 1821
Genus Aepycamelus Macdonald, 1956
Aepycamelus proceras Matthew and Cook, 1909

LOCALITY AND REFERRED SPECIMENS: MV8414-UM8491, fragments of cervical vertebrae; UM8492, unidentified bone fragments; UM8493, left astragulus; UM8495, proximal phalanx; UM8494, broken left magnum and right magnum; UM8496, left cuneiform; UM8497, left unciform; UM8498, right and left trapezoid; UM8499, left lunar; UM8500, metatarsal III and IV; UM8501, skull with left I^3-P^1, P^4-M^3; right I^3-M^3; MV6003-UM8520, right M^2.

DESCRIPTION: Dentition: I^3-P^1 fairly prominent, single-rooted, moderately long, peg-like; I^3 separated from C by short diastema; P^1 broken but appears to be double-rooted; P^3 long, narrow bears cingulum-like ridges on internal wall of tooth; posterior

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end of ridge closed, forming small fossette; P^4 long and narrow, with long, narrow fossette; molars large, simple, typically camelid with moderately high crowns, very strong styles, well-developed folds on external enamel walls.

Limb elements: Metatarsal III and IV extremely elongate; large size of assorted carpals and tarsals suggests camel of large size.

COMPARISON: All material listed except UM8520 was taken from the same quarry hole, making it very probable that the material is all from one individual.

A review of papers dealing with camels by Macdonald (1966) produced a chart that lists characteristics which may be used in distinguishing four common Barstovian camelid genera--*Procamelus*, *Pliauchenia*, *Hesperocamelus*, and *Aepycamelus*. The North Boulder River basin material compares closely to *Aepycamelus* according to this chart.

UM8501 (a skull) can be separated from *Pliauchenia* by the retention of P^2, which is absent in *Pliauchenia* (Macdonald, 1966). I^3-P^1 are well-developed in UM8501, unlike *Hesperocamelus*, which has simple peg-like forms (Macdonald, 1966). UM8500, a metatarsal (III and IV), is extremely elongate, much longer than the moderately

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elongate metatarsals of *Hesperocamelus* and *Procamelus* (Henshaw, 1942; Macdonald, 1966). At the species level, the UM material compares closely in dentition and limb size to *Aepycamelus proceras*. The absence of I^1-I^2 and the exceptionally elongate metatarsal (III and IV) distinguish it from *A. stocki*, although the tooth row is similar in the latter (see below).

Measurements of *Aepycamelus proceras* dentition

	UM8501	*A. proceras*[a]	*A. stocki*[b]
M^1-M^3	90.2	98	96
P^3, a-p	20.1	20	19
tr	12.3	12	11.4
P^4, a-p	20.8	20	18.0
tr	17.6	19	17.5
M^1, a-p	27.8	23	27.0
tr	24.6	22	22.0
M^2, a-p	35.1	33	35.5
tr	28.9	28.5	24.0
M^3, a-p	34.1	34	36.8
tr	25.8	27	21.0

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Measurements of Aepycamelus proceras metatarsal III and IV.

	UM8500[c]	A. proceras[a]	A. stocki[b]
Total length	538	552	407
Tr - proximal	55.1	53	51
Tr - distal	63.4	73	---

[a] AMNH14070 from Lower Snake Creek beds, Nebraska (Matthew and Cook, 1909).

[b] CIT1434, 2827 from Tonopah, Nevada (Henshaw, 1942).

[c] Metatarsal missing portion of middle section but continuity of width of shaft suggests a short length is missing. Measurement should be considered a minimum length but close to total.

Aepycamelus sp.

LOCALITIES AND REFERRED SPECIMENS: MV6003-FAMNH36830, unknown material; MV8414-FAMNH36814, unknown material.

DISCUSSION: Material of unknown composition, part of AMNH collection only.

camelid
gen. and sp. indet.

LOCALITIES AND REFERRED SPECIMENS: MV8417-UM8586, broken phalanx; UM8587, left magnum; UM8588, right mesocuneiform; UM8585, left mesocuneiform; UM8563, metatarsal fragments; MV8418-UM8595, broken right

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astragulus; MV8414-UM8513, proximal phalanx; UM 8512, left magnum; MV6003-UM5120, podial elements; UM8539, left mesocuneiform; UM8543, right unciform; UM8544, right scaphoid; UM8541, right unciform; UM8542, broken left unciform; UM8538, right astragulus; UM8537, distal end of metatarsal; UM8536, left cuboid.

Family ANTILOCAPRIDAE Gray, 1866
Genus Merycodus Leidy, 1854
cf. Merycodus

LOCALITY AND REFERRED SPECIMENS: MV6003-UM3167, fragments of right ramus with M_1 and P_2; UM0531, left M_3; UM0892, horn fragment; UM8540, horn fragments.

Paracosoryx sp.

LOCALITY AND REFERRED SPECIMEN: MV6003--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

Merriamoceras sp.

LOCALITY AND REFERRED SEPCIMEN: MV6003--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

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Family CERVIDAE Gray, 1821
Genus *Rakomeryx*
Rakomeryx kinseyi

LOCALITY AND REFERRED SPECIMEN: MV6003-FAMNH34193.

DISCUSSION: Material of unknown composition, part of AMNH collection only.

Genus *Dromomeryx*
cf. *Dromomeryx borealis*

LOCALITY AND REFERRED SPECIMEN: MV8414--no number.

DISCUSSION: Material of unknown composition, part of AMNH collection only, museum number not available.

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APPENDIX II

GENERAL DESCRIPTION OF TERTIARY SEDIMENT TYPES FROM PLATE I.

Bedding thickness follows this system:

Very thick	3.0 - 1.0 m
Thick	1.0 - 0.3 m
Medium	0.3 - 0.1 m
Thin	0.1 m - 1.0 cm
Very thin	Less than 1.0 cm

Ts_1 Tuffaceous Siltstone, light brown to grayish-white, very fine-grained, well sorted, composition (ave.) 85% unaltered and devitrified glass shards, 8% quartz, 5% biotite, 2% magnetite. Silica cement (rarely calcite), calcareous nodules (ave. 5 x 12 cm) rare but abundant when present. Poorly exposed, very thick to thick massive tabular beds that appear to be continuous. Commonly contains lenses of Tc_2. Vertebrate fossils rare but well-preserved when present.

Ts_2 Clay-Rich Siltstone, white-gray to brown-gray, fine-grained, well sorted, composition (ave.) 60% devitrified glass and clay (montmorillonite), 20% quartz, 10% biotite, 10% various including magnetite, hornblende and chert. Very poorly exposed,

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very thick to thick massive tabular beds that are laterally continuous. Swells when wet, weathers to irregular "popcorn" surface.

Ts_3 Red Siltstone, red to pink, very fine-grained, well sorted, composition (as per Ts_1, except 10% clay (kaolinite)), calcite cemented. Poorly to moderately exposed, very thick to thick masive tabnular beds. Contains lenses of Tc_2. Vertebrate fossils rare and poorly preserved.

Tss Quartz Sandstone, white-gray, fine- to medium-grained, moderately well sorted, composition (ave.) 50% quartz, 25% biotite, 15% devitrified glass, 10% others including feldspar, hornblende and chert, grains rounded to angular, biotite books common. Very poorly exposed, very thick to medium bedded lensoidal sets of massive to thick planar laminations. Some lenses contain indistinct planar cross-laminations.

Tsp Siltstone with Pebbles, brown to light brown, bimodal silt and sand with cobbles, pebbles and rarely boulders, poorly sorted, matrix supported, composition (ave.): silt and sand--80% devitrified glass, 20% others including quartz, hornblende, biotite, chert

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and magnetite; cobbles and pebbles--as per Tc_2, Tc_3, or Tc_4 with clasts, subangular to subrounded. Moderately to well exposed, very thick to medium massive tabular beds, beds continuous for up to 700 meters in best exposures. Normal and reverse graded, clasts rarely imbricated, commonly contains angular ripups (1-8 cm) of itself and Tsh, silicified root casts abundant locally. Contains lenses and interbedded with Tc_2, c_3 and c_4, lenses exhibit cut and fill structure, also interbedded with Tsh. Vertebrate fossils locally abundant and well preserved.

Tsh Tuffaceous Shale, brown to gray, as per the fine fraction of Tsp. Moderately to well exposed thin to thickly bedded tabular sets of thick to very thin laminations, thin lenses with sets of planar to tangential cross-laminations common. Bedding abruptly scoured and terminated by Tsp units, when not scoured beds are continuous for the length of outcrop. Interbedded with Tsp.

Tm Mudstone, variegated green-gray, red and brown-gray, very fine-grained, very well sorted, composition (ave.) 60% devitrified glass with clay (montmorillonite), 20% quartz, 15% biotite, 5% others. Poorly exposed,

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very thick, massive tabular beds. Locally contains abundant calcareous nodules which vary from 1-2 cm to 30 cm in diameter. Vertebrate fossils rare.

Ta Ash, gray-white, very fine grained, very well sorted, composition (ave.) 90-100% unaltered and devitrified glass shards, 0-10% others including quartz, biotite, and magnetite. Poorly exposed, medium to thin massive tabular beds, rarely finely laminated with silt-mud drapes. Calcite nodules rare but locally abundant where present.

Tt Calcareous Tufa, white-gray, cryptocrystalline calcite, porous with voids ringed with very fine calcite crystals. Contains matrix supported clasts of Kem and Paleozoic carbonates. Well exposed in a structureless (12 x 4 m) mass in one case; in the only other occurrence it forms a thick featureless bed and also permeates through cracks in an underlying Ts_1 unit to form a boxwork structure.

Tc_1 Conrow Creek Conglomerate, very poorly sorted, bimodal, fine fraction is sand and silt composed of quartz, chert and other lithic grains, coarse fraction (boulders-cobbles) is matrix-supported,

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subangular to subrounded, 99% Paleozoic carbonates and shales, 1% Kem. Well exposed, no bedding or sedimentary structures, 10 to 20 m thick, calcite cemented.

Tc_2 Granitic-Lithic Conglomerate, dirty gray to brown-gray, silt-sand to medium pebbles, cobbles rare, subangular to rounded, moderately to poorly sorted, clast composition very variable (ave.) 50% GRF, 30% LRF, and 20% Kem. Silt-sand composiion quartz, biotite, devitrified glass and feldspar abundant; hornblende, magnetite, obsidian, and chert are minor constituents. Well to moderately exposed, thick to thin lensoidal beds about 6 to 10 m wide, usually planar to trough cross-bedded. Normal grading from scoured base common, cut and fill structures, fining upward sequences rare. Some beds composed almost entirely of white pumice pebbles. Best exposures calcite cemented. Rarely exposed as 4 m thick, 50 m wide outcrops with medium to rarely thick-bedded lensoidal to wedge sets of planar to trough cross-laminations. Commonly interbedded with Tm, Ts_2, Tsp, and Tss.

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Tc_3 Carbonate Conglomerate, gray to blackish-gray, silt-sand to large cobbles, very poorly sorted, angular to rounded clasts, clast-supported, clast composition (ave.) 80% Paleozoic carbonates, 10% Kem, 10% others including quartzite, shale, and chert. Silt-sand composition smaller grains of the coarse fraction with quartz and devitrified glass. Moderately to well exposed, very thick to medium bedded wedge to tabular sets of planar to trough cross-laminations, some sets planar laminated (very thick) with imbricated clasts, thin bedded set of trough cross-laminated coarse sand common. Cut and fill structures and graded bedding common. Usually calcite cemented.

Tc_4 Kem Conglomerate, as per Tc_3 except clast composition (ave.) 95% Kem, 5% other including Paleozoic carbonates and shales.

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